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DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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COAL RESOURCES OF THE SUSITNA LOWLAND, ALASKA

by

R. D. Merritt

STATE OF ALASKA
Department of Natural Resources
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

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COAL RESOURCES OF THE SUSITNA LOWLAND, ALASKA

by
Roy D. Merritt[1]

ABSTRACT

The Susitna lowland of southcentral Alaska contains major reserves of subbituminous and lignite coals within the Kenai Group of Tertiary age; these reserves occur mainly in the Tyonek Formation. The Susitna lowland contains the second largest coal-resource base in Alaska, surpassed only by the northern Alaska deposits. Estimates of resources and reserves vary widely, but total minable reserves are undoubtedly several billion tons. Most of the known resources occur in a crescent-shaped belt along western and southern margins of the Susitna lowland.

Kenai Group coals formed in paleoenvironments associated with continental fluvial depositional systems. Rapid lateral and vertical changes in lithology often make correlation of coal beds difficult, even over distances of 1,000 m. Petrologic studies indicate that most of the Susitna lowland coals originated in forest-moor environments during a fairly temperate (warm and moist) climatic period. Peat-forming episodes that occurred during lulls in regional tectonic activity were interrupted by the rejuvenation of adjacent highlands of low to moderate relief and the shedding of clastic sediments into backswamps.

Susitna lowland coals are comparable in overall quality with those of the Powder River basin of the western United States. The sulfur content of Susitna lowland coals is extremely low, ≤0.3 percent, and ash content is variable but averages about 15 percent; mean heating value is about 8,200 Btu/lb (all on as-received basis). Concentrations of trace elements that could volatilize during combustion, such as mercury, antimony, uranium, and thorium, are relatively low, but sodium, vanadium, and barium sometimes occur at higher levels.

Coal overburdens of the region are also low in pyrite and sulfur (<0.5 percent); as with the coals, sulfur occurs mainly in the organic species. Minor quantities of framboidal pyrite, present as pyritic sulfur, were documented in certain overburden samples. Some overburden samples had relatively high percentages of the trace elements boron, lead, zinc, molybdenum, nickel, cobalt, and cadmium. However, the serious acid conditions commonly associated with eastern and midwestern U.S. coal mines and the high levels of soluble salts and adsorbed sodium in western U.S. coalfields are not likely to be significant problems.

Large-scale surface mining in the Susitna lowland will probably begin within the next decade. At that time, material textures in mine spoils, particularly clays and weathered gleys, may become a significant problem for proper drainage and revegetation on certain tracts. In addition, stream siltation may occur locally; in areas of perched ground water or springs, de-watering of trenches and pits will be necessary.

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INTRODUCTION

Government and industry have sporadically investigated Alaska coals since about 1900. Uniform resource and reserve figures and information on geology and extent of most occurrences are scarce, but existing evidence indicates extensive coal resources in Alaska. In 1979, U.S. Department of Energy reported a demonstrated Alaskan coal-reserve base of 6 billion tons. In contrast to the Cook Inlet and the Kenai Peninsula, which have been extensively drilled for oil and gas and intensely studied, the subsurface of the Susitna lowland is relatively unexplored, and its structure and stratigraphy are poorly understood. Estimates of total coal resources--inferred and hypothetical--have varied from 2 to 5.5 trillion tons (McConkey and others, 1977).

Despite these immense resources, coal production has been minimal because of the remoteness of deposits and lack of markets. During the early part of this century coal was produced on a small scale from numerous sites for local use and for ship fuel; substantial quantities were produced from the Matanuska coalfield (fig. 1) for the Anchorage market until natural gas from Cook Inlet supplanted it in 1967 (Conwell, 1972b). Coal production in Alaska is limited now to the Usibelli Mine, which produced about 1.5 million tons from the Hosanna Creek field of the Nenana basin in 1986.

The high cost of petroleum fuels and uncertainty of supply have created strong interest in Alaska's coal resources and their feasibility for local use, export, and generation of synthetic fuels. Accordingly, DGGS is investigating and assessing coal resources of the state.

The purposes of these investigations are to aid in land classification and management, to facilitate issuance of coal-prospecting permits and coal leases, to determine more accurately the extent of coal reserves and their potential for development, to address numerous inquiries from industries who are interested in developing the resources and from Pacific Rim countries seeking coal supplies, and to provide a single information source on coal deposits of an area.

The first region selected for study is the Susitna lowland, a broad area drained by the Susitna River and its tributaries. Beds of subbituminous and lignite coal exposed along major drainages of the lowland and southern foothills of the Alaska Range indicate abundant, relatively shallow, subsurface coal deposits. Exploratory drilling by leaseholders in the southwestern Susitna lowland has proved major coal reserves suitable for surface mining. Barnes (1966) estimated the coal resources within the Beluga-Yentna region at 2.4 billion tons in beds over 0.75 m thick; of these resources, 2.1 billion tons are concentrated in the Beluga and Chuitna River basins.

The strategic location near tidewater, the thickness, extent and quality of the numerous coal seams, and characteristics of the overburden, the interburden, and the seatrock combine to make deposits of the Susitna lowland--and particularly those in the southern area--the most economically attractive for near-term, new-mine development in Alaska. Coals of the Matanuska field will undoubtedly be mined anew in the near future, and these could be blended with the lower-Btu coals of the Susitna lowland to upgrade the product.

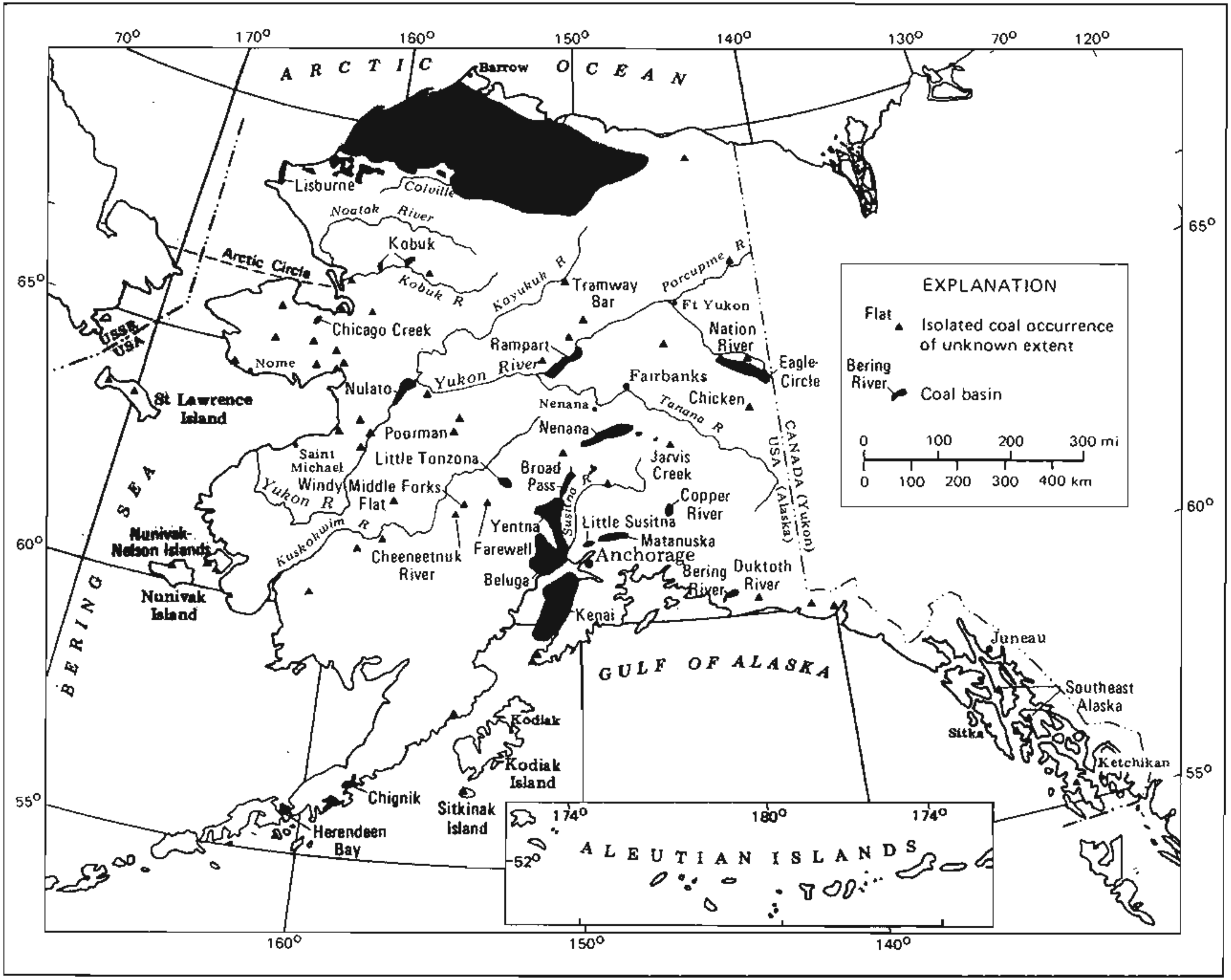

Figure 1. Location map of major coal basins and isolated coal occurrences in Alaska. Modified from Barnes (1967) and Conwell (1977a).

The Susitna lowland contains several coalfields, all of which are of similar age and character. Because discontinuous outcrops and lack of subsurface data preclude detailed study for most of the lowland, this study will focus on regional basin analysis.

The Susitna lowland was selected for three reasons: (1) it contains the Capps and Chuitna districts of the Beluga coalfield, which have the highest potential for near-term large-scale production in Alaska; (2) enough geologic data exist to make the preliminary compilation without extensive field work; and (3) the state has received numerous applications for coal-prospecting permits and needs information on that area's coal potential.

Location and settlements

The entire Cook Inlet-Susitna lowland Tertiary province (Wahrhaftig, 1965) is about 515 km long by 130 km wide. The Susitna lowland encompasses about 13,000 km^2 (fig. 2). Bounded by the arcuate Alaska Range on the north and west, the Talkeetna Mountains on the east, and Cook Inlet on the south, the lowland extends from the Matanuska-Susitna Borough into the Kenai Peninsula Borough (fig. 3). Because the Susitna lowland includes the northern part of Cook Inlet, some authors (Miller and others, 1959) have considered it the northwestern extension of the Cook Inlet Tertiary basin. Barnes (1966) called the area the Beluga-Yentna region. Elevation ranges from sea level at Cook Inlet to about 300 m at the northern margin. Isolated uplands of intrusive and pre-Tertiary rocks rise to 1,200 m above surrounding lowlands.

The Castle Mountain fault, a major northeast-trending discontinuity, separates upper Cook Inlet on the south and the Susitna lowland on the north. Most stratigraphic studies in the Cook Inlet petroleum province terminate at the fault; however, important coal leases in the Beluga field lie on both sides of the fault zone. Work during the past several years by leaseholders in the southwestern part of the lowland indicates the Beluga coalfield contains three separate coal deposits: Capps, Chuitna, and Threemile districts.

The upper Cook Inlet region, site of metropolitan Anchorage and nearby settlements in the Matanuska Valley and Kenai Peninsula, is the most densely populated region in Alaska. The state's principal agricultural region is located in lower Matanuska Valley, and additional lands are being readied for agriculture near MacKenzie Point, across Knik Arm from Anchorage. Except for small settlements along the Parks Highway and the Alaska Railroad, the Susitna lowland is essentially uninhabited. Summer activity includes placer mining in the Petersville-Cache Creek area in the northern part of the lowland and drilling on the active coal leases in the southwestern lowland.

Access

The Parks Highway and the Alaska Railroad transect the Susitna lowland in a north-south direction roughly paralleling the Susitna River, connect the ports at Anchorage and Seward with Fairbanks in the interior, and pass through the Susitna, Matanuska, and Broad Pass coalfields (fig. 3). Because of accessibility to rail and ocean transportation, the Susitna lowland has been a main coal-exploration target of industry. The Parks Highway and a 16-km-long extension to Talkeetna are the main paved roads in the area. A 50-km-long gravel

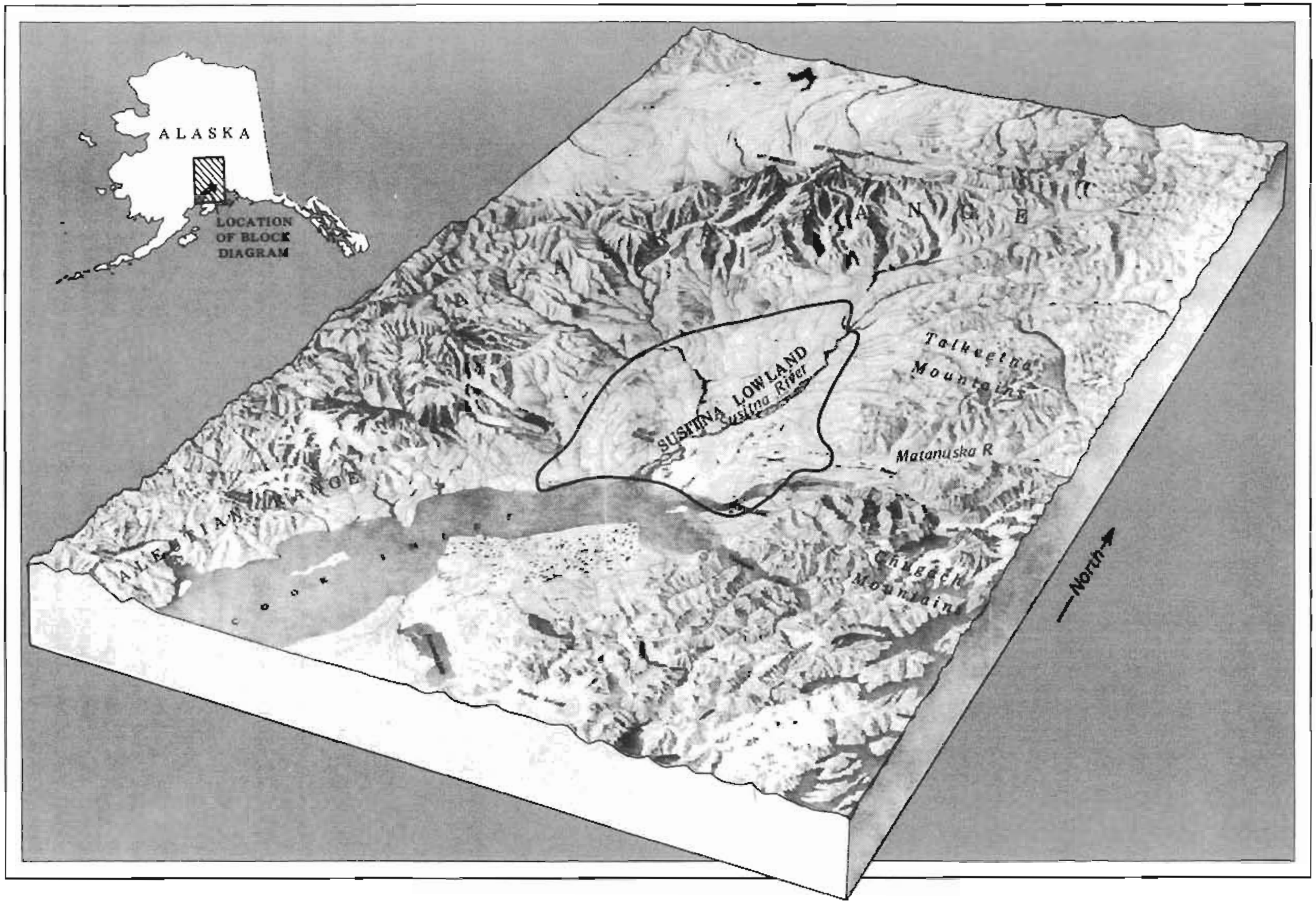

Figure 2. Perspective block diagram showing general location and physiographic setting of the Susitna lowland. Modified from Miller and Dobrovolny (1959). Vertical exaggeration about 4x.

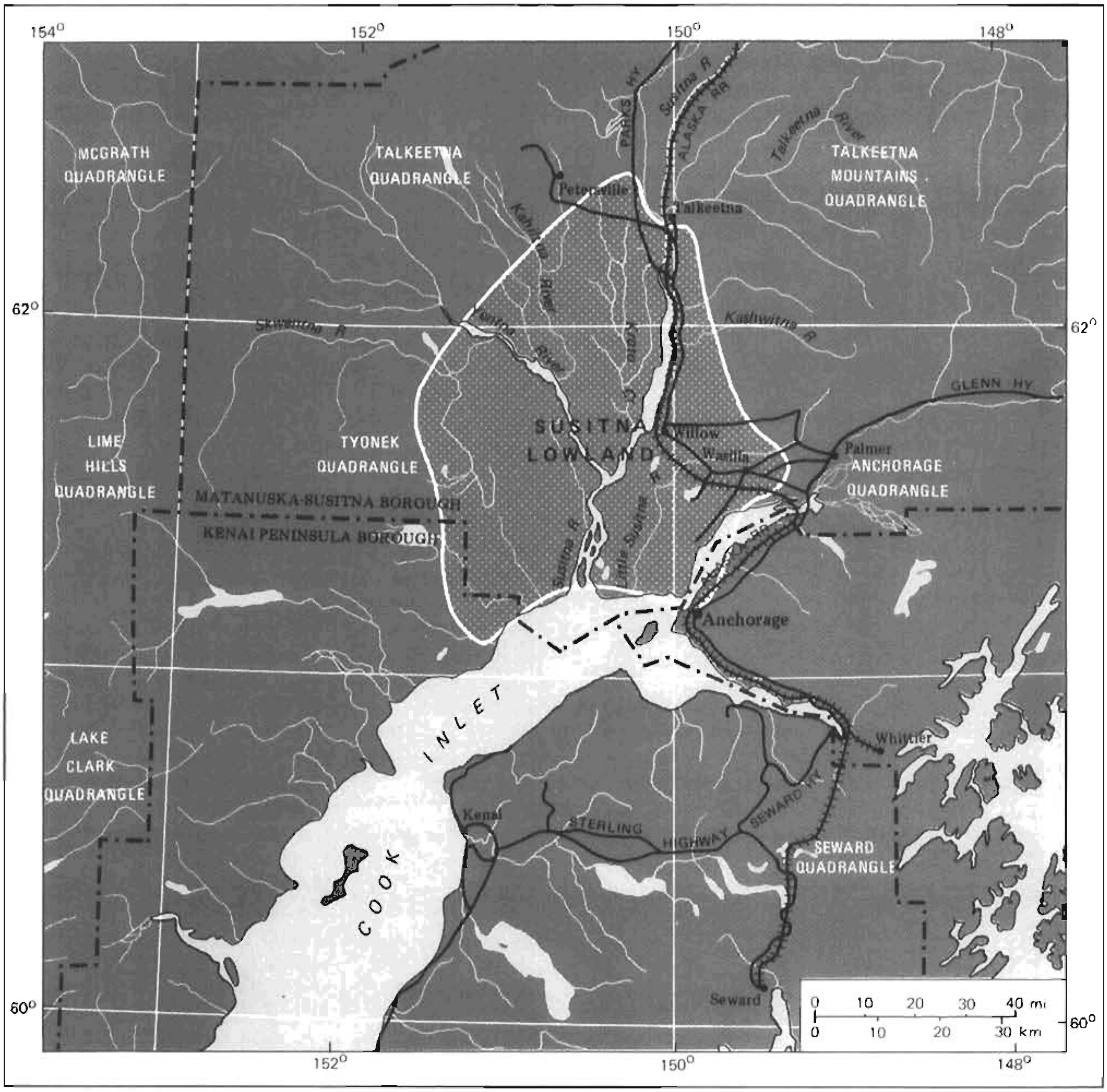

Figure 3. Regional index map showing main geographic features, transportation routes, and major political boundaries in southcentral Alaska.

road connects the placer-mining district on Peters and Cache Creeks northwest of Talkeetna with the Parks Highway. Most of the remaining lowland is accessible only by aircraft or riverboat; helicopters are generally used for field investigations. Surface conditions and environmental restrictions limit the use of off-road vehicles. A few private landing strips of varying quality lie near some of the mining claims, but permission is required for their use. Public facilities are available at Talkeetna.

Climate

The climate in the Susitna lowland is less severe than in the interior, but heavy snowfalls and strong winds are not unusual during winter. Average annual precipitation at Talkeetna is 71 cm, and the mean temperature is about 0°C; Anchorage International Airport averages are 38 cm and 2°C, respectively (U.S. Department of Commerce, 1968).

Ferrians (1965) indicated that the lower areas of the southern Susitna lowland are generally free of permafrost. Permafrost occurs in isolated masses at intermediate elevations and is discontinuous in the mountains.

Physiography

The terrain of the central Susitna lowland is broad, relatively flat to slightly irregular, and increases in relief toward the foothills. Schmoll and Yehle (1978) classified the physiographic and geologic features of the Beluga area into: (1) high mountains and foothills of Mesozoic and Lower Tertiary metamorphic and igneous rocks; (2) an adjacent plateau underlain primarily by Tertiary coal-bearing rocks with a generally thin, discontinuous cover of Quaternary-Tertiary(?) glacial deposits; and (3) lowlands underlain by thick Quaternary deposits--principally estuarine and fluvial--that are separated from the plateau by major escarpments.

Large glaciers approach the margins of the Susitna lowland. During Pleistocene time, at least five glaciations affected the lowland (Karlstrom, 1964; Nelson and Reed, 1978); evidence indicates that ice filled upper Cook Inlet to elevations of over 1,200 m (Karlstrom, 1965). Retreating glaciers from the Susitna lowland left a landscape dominated by fluted moraines, drumlins, kettle lakes, ponds, marshes, bogs, and scoured bedrock (Karlstrom, 1965). Periglacial activity and mass movement created valley features of talus slopes, landslides, avalanche chutes, and rock glaciers. Fluvial and other processes continue to modify the floor of the lowland.

Previous work

Geologic investigations and reports of coal in the Susitna lowland were made by the U.S. Geological Survey as early as 1900 (Barnes, 1966). Various factors--the 1957 discovery of oil and gas in the Cook Inlet basin at Swanson River, an increased interest in the coal and agricultural potential of the region, land selections under the Alaska Statehood Act and the Alaska Native Claims Settlement Act, and attempts to move the state capital to Willow--have resulted in numerous reports on the environment and resources of the region; many are cited in this report. The most thorough report published on coal in the Susitna lowland is by Barnes (1966).

Acknowledgments

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Office (Anchorage), D.R. Maneval, University of Alaska School of Mineral Industry, and R.D. Reger (DGGS) carefully reviewed the original manuscript and made many helpful suggestions. J.E. Sperber took the outcrop photographs and prepared the detailed bibliography. G.K. Tommos performed the petrographic modal analyses on overburden rock samples. M.A. Belowich and K.L. MacDonald drafted several text figures. Tables and appendixes were typeset by R. A. Mann (DGGS). Final editing, layout, and production was performed by A.F. Seward (DGGS).

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STRUCTURAL GEOLOGY AND REGIONAL TECTONISM

The Susitna lowland is an embayment or extension of the Cook Inlet back arc basin, or intermontane half graben. Kelly (1963) concluded that the lowland is separated from the Cook Inlet basin by a partially buried ridge of granitic rocks. The major synclinal axis of the Cook Inlet basin bifurcates northward; one arm extends into the Yentna region, the other northeastward into the Matanuska Valley. These pull-apart extensional basins, or rift valleys, are typically filled with continental deposits and characterized by numerous discontinuous coal seams.

Payne (1955) recognized five arcuate Mesozoic tectonic elements in southcentral Alaska: (1) the Chugach Mountains geosyncline, (2) the Seldovia geanticline, (3) the Matanuska geosyncline, (4) the Talkeetna geanticline, and (5) the Alaska Range geosyncline (fig. 4). The Shelikof Trough, which includes the Susitna lowland, is a Cenozoic structure superimposed on these five Mesozoic features. During widespread orogeny at the end of the Cretaceous Period, the Talkeetna Mountains restricted part of the Matanuska geosyncline and became the eastern boundary of Shelikof Trough (Gates and Gryc, 1963).

According to Hackett (1976a, 1977), Tertiary basins of the upper Cook Inlet region represent a system of tilted horsts and grabens produced by extensional fragmentation of a pre-Tertiary basement (fig. 5). He postulated that substantial translational and rotational block movements occurred in southcentral Alaska during Late Cretaceous and early Tertiary time, caused by a change from normal to oblique subduction between major plates (1976a). Continued oblique rifting during middle to late Tertiary time further accentuated these basins. Hackett (1977) recognized several subbasins within the region and interpreted the Cook Inlet, Beluga, and Yentna basins as rhombochasms; that is, parallel-sided gaps in the crust caused by dilation (fig. 6). In dextral rhombochasms, the crustal blocks are moved apart with a right-hand lateral component. Hackett interpreted the Susitna basin and the Matanuska Valley as sphenochasms, or triangular gaps separating two crustal blocks with fault margins that converge to a point. Carey (1958) concluded that a sphenochasm originates from rotation of one of the blocks.

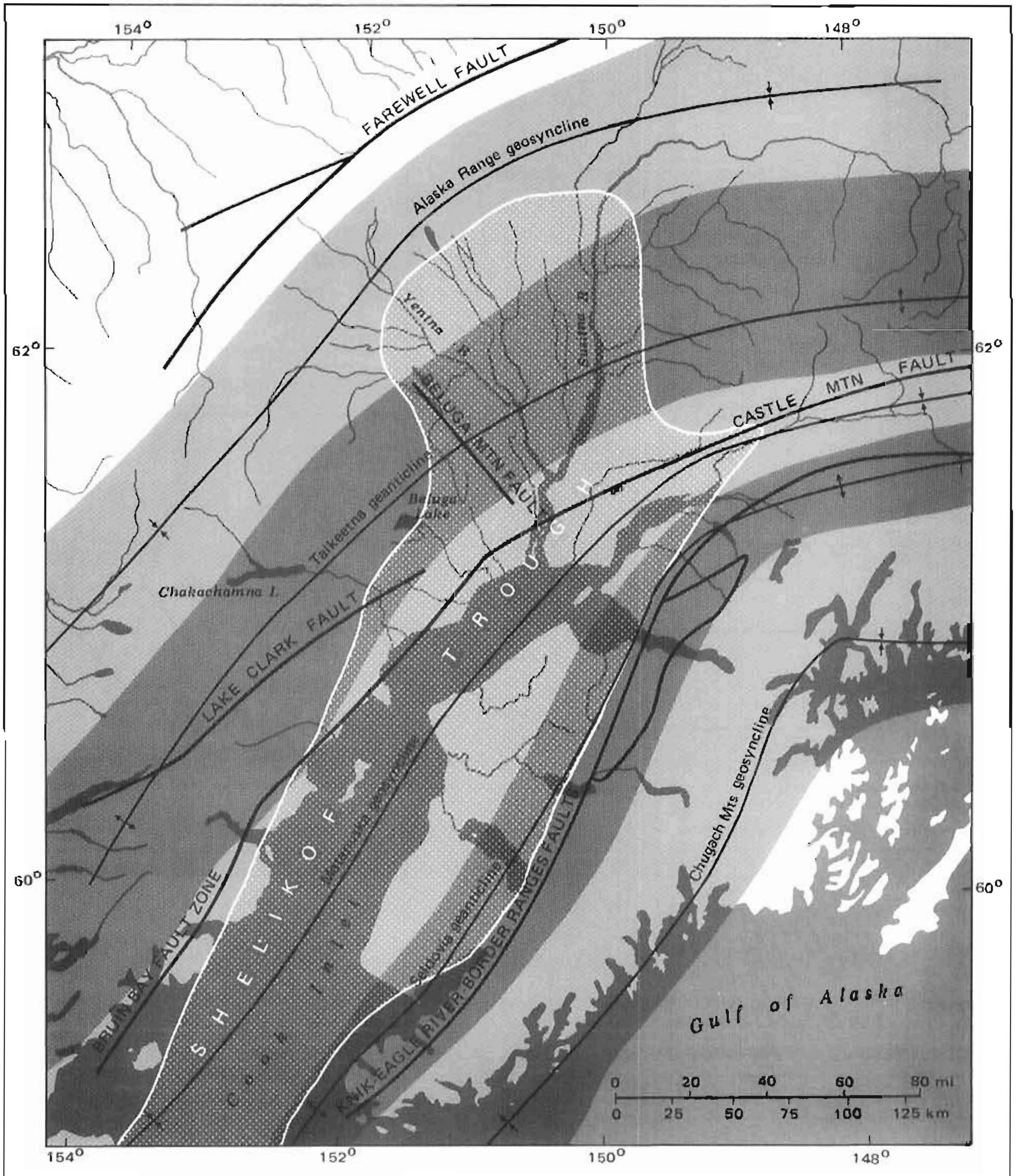


Figure 4. Major tectonic elements that outline the geologic setting of southcentral Alaska. Modified from Payne (1955); Hackett (1976a).

In Hackett's (1977) simple Bouguer gravity map of the southern Susitna lowland (fig. 7), gravity highs correlate with exposures of pre-Tertiary basement rocks, and gravity lows indicate areas underlain by Tertiary sediments. Relief on the pre-Tertiary basement surface generates the larger anomalies

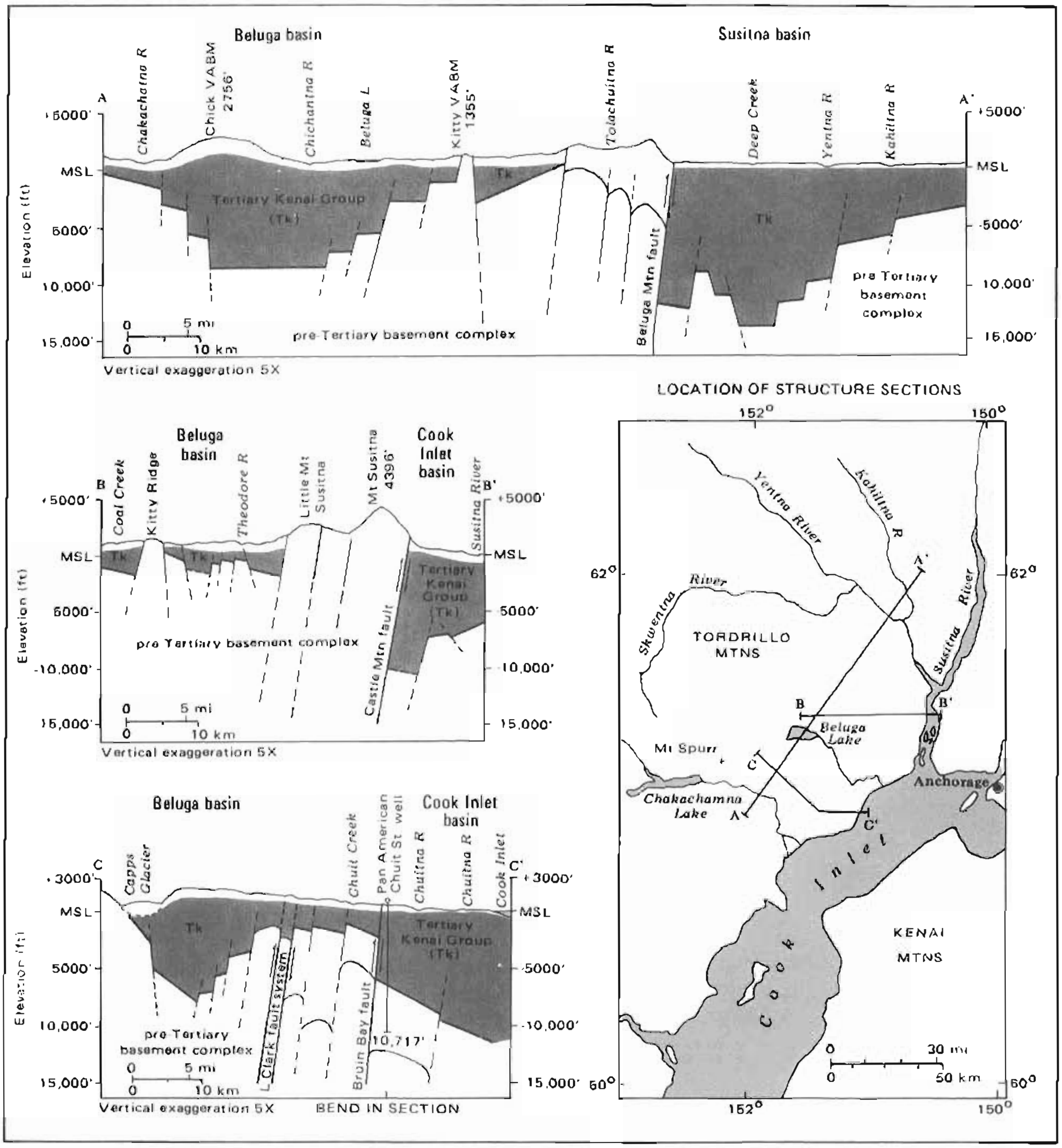


Figure 5. Structure sections based on geophysical profiles across the Beluga basin and adjacent areas. From Hackett (1977).

over the lowland. The Beluga, Susitna, and Yentna basins are characterized by steep gravity gradients and low Bouguer anomalies which indicate the presence of large basement discontinuities where deep tectonic basins form. The regional gravity gradient over the upper Cook Inlet region infers a gradual westward thickening of the earth's crust (Barnes, 1966; Hackett, 1977). The Castle Mountain fault bends or splays into the Bruin Bay fault zone south of the Lake

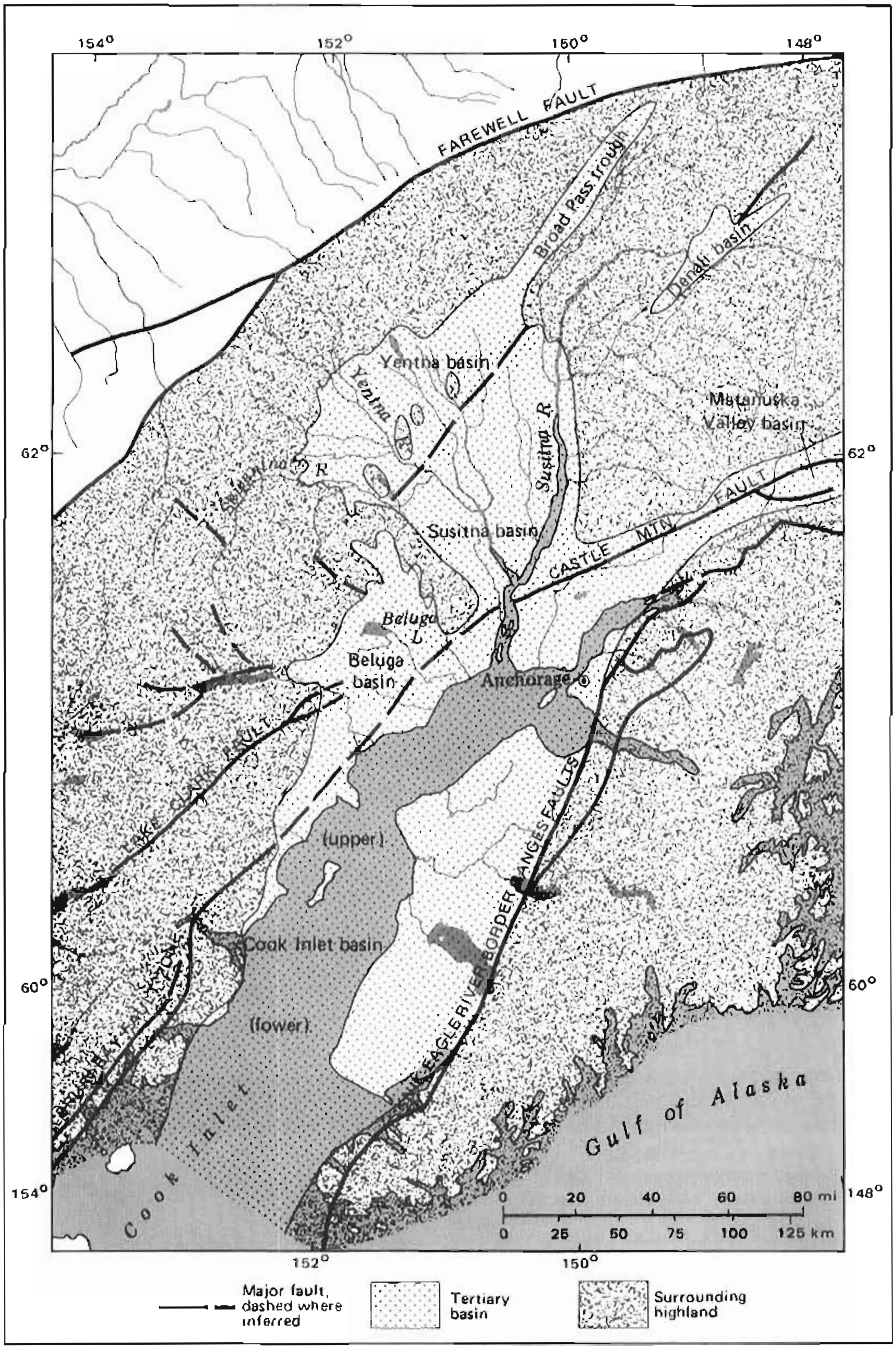


Figure 6. Major Tertiary basins of the Cook Inlet-Susitna lowland. From Hackett (1977).

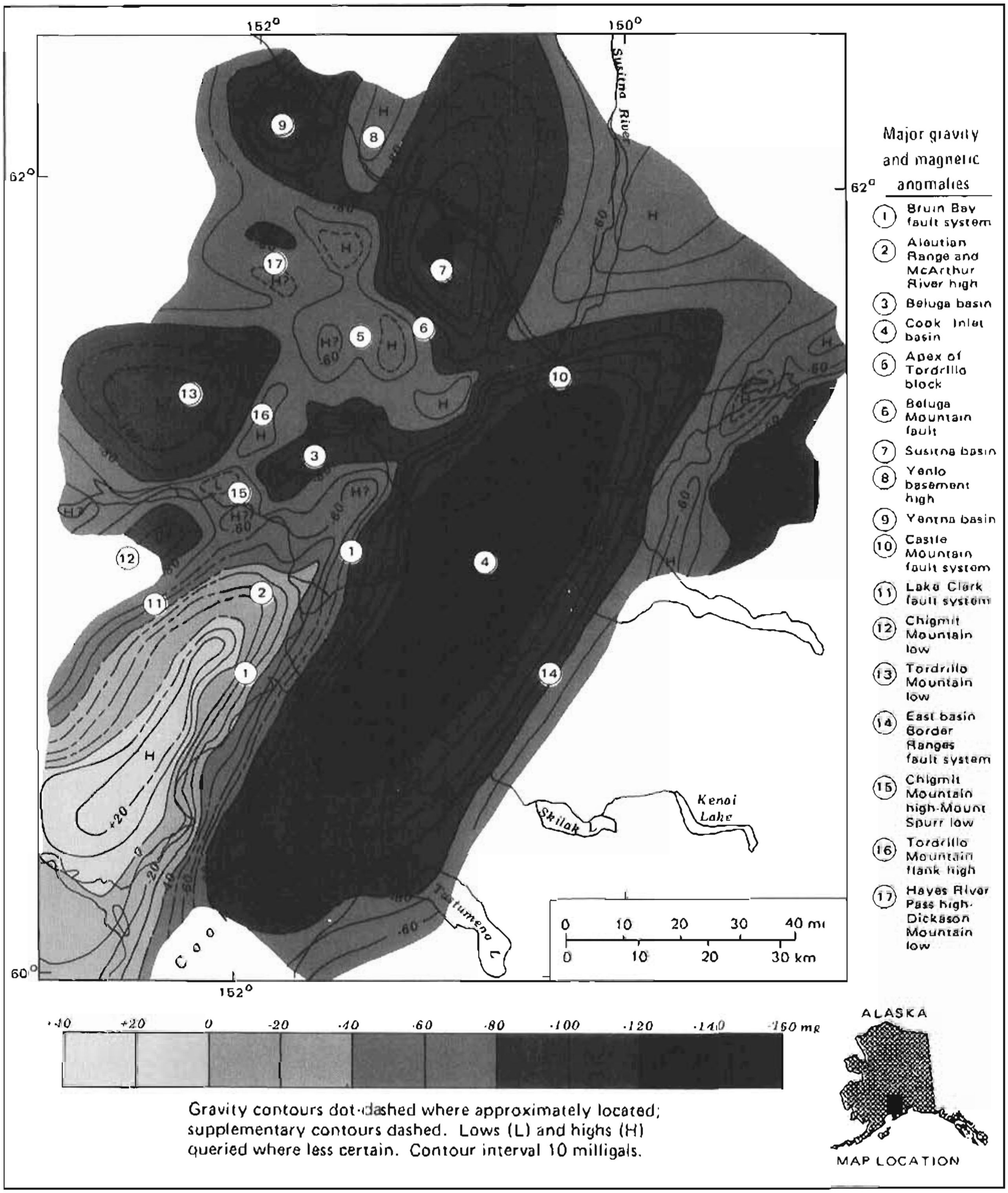


Figure 7. Simple Bouguer gravity map of the Beluga basin and adjacent area. From Hackett (1977).

Clark fault (fig. 8); it is thought not to continue west-southwest into the Lake Clark fault as originally inferred. The Beluga Mountain fault trends northwest along the Beluga Mountain-Mount Susitna front and Susitna lowland

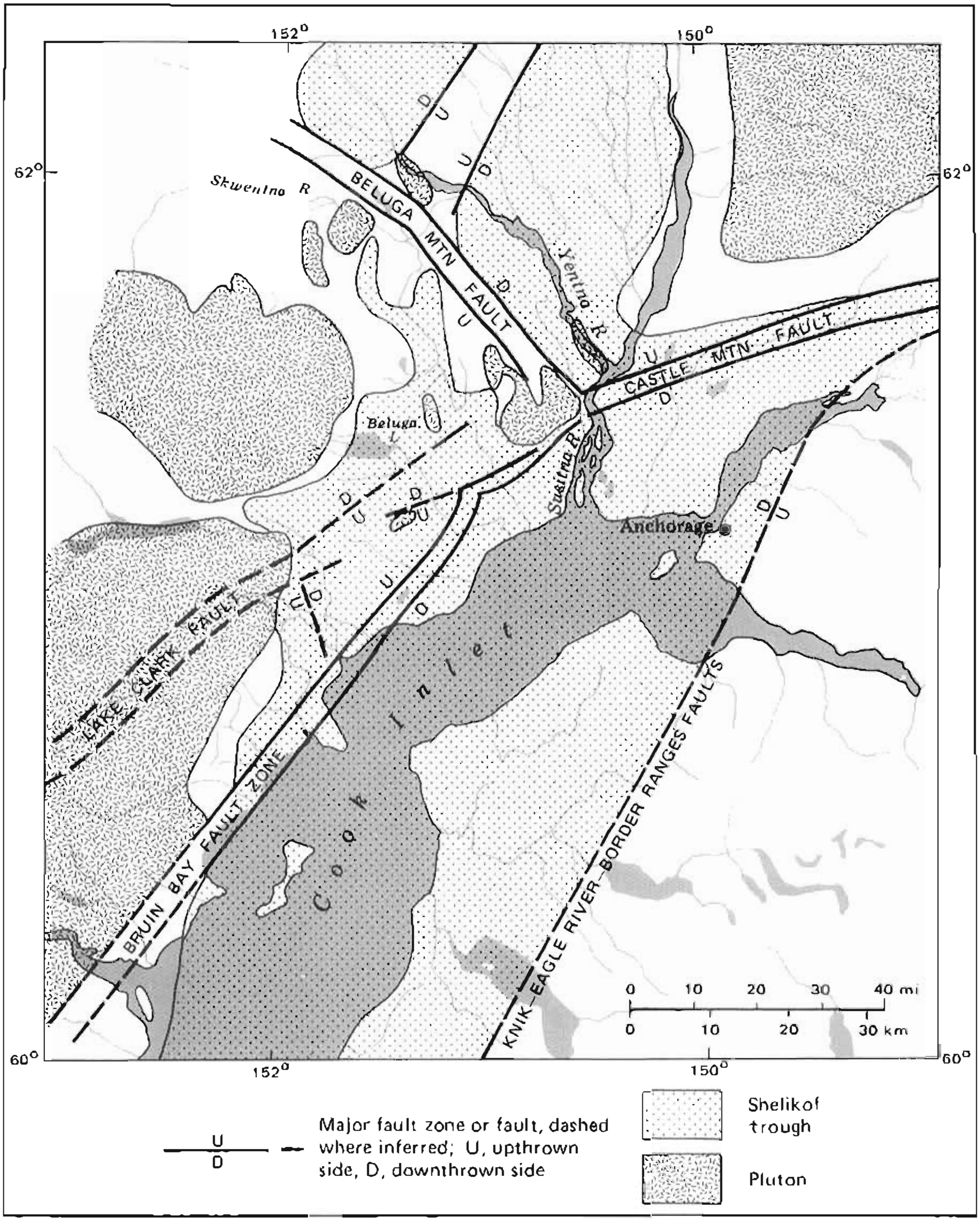


Figure 8. Major fault systems in the Shelikof trough with basin outlines. Modified from Hackett (1976b).

boundary; Hackett (1977) interpreted it as a high-angle, 60°- to 75°-dipping, reverse fault upthrown on the southwest, with a vertical displacement of over 3,000 m. The Castle Mountain fault, clearly visible as a surface lineament crossing the Susitna Flats (Kirschner and Lyon, 1973), displays dextral strike-slip movement or right-lateral drag, as evidenced by offset stream drainages.

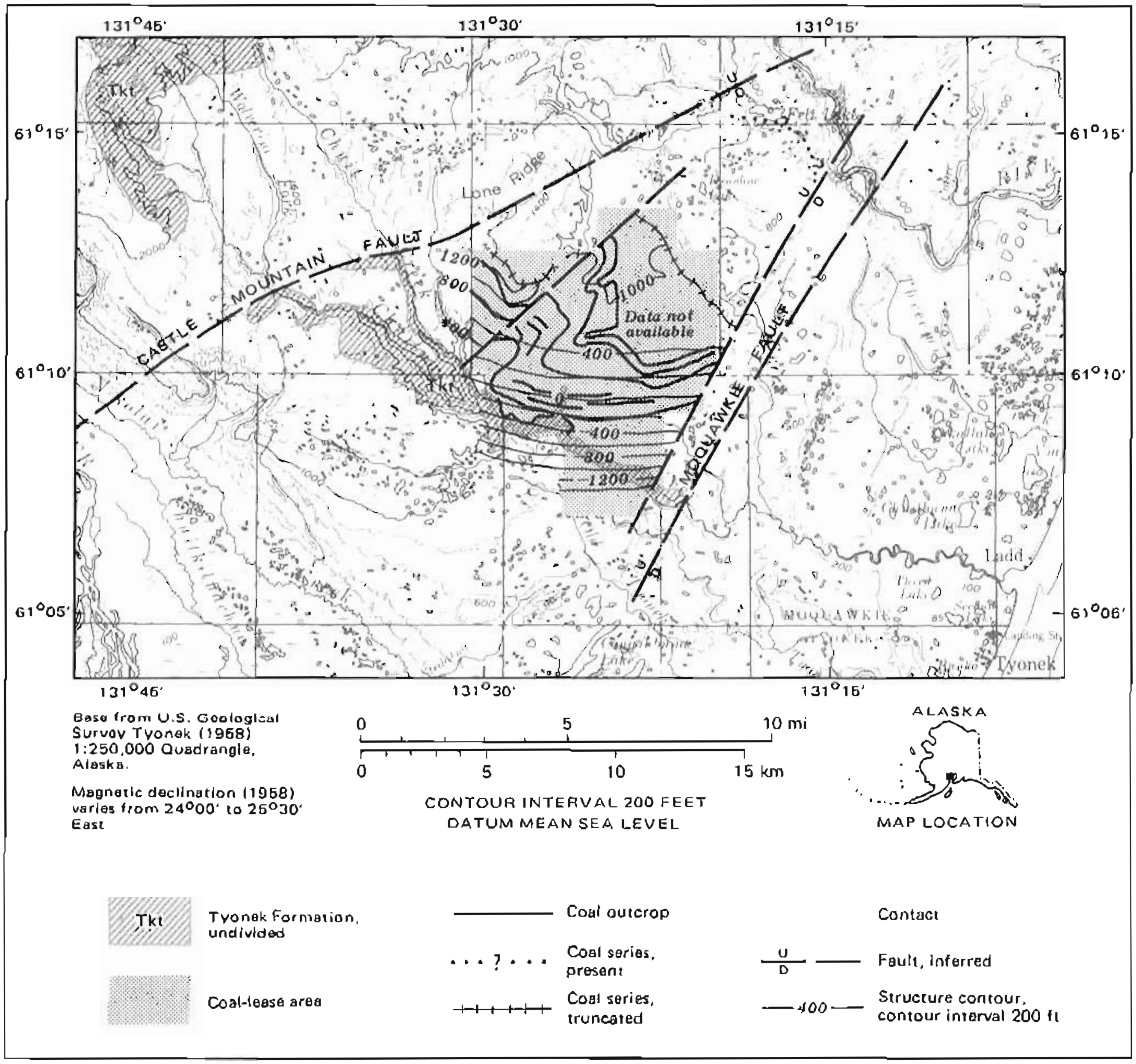


Figure 9. Structure contours, coal outcrops, and coal lease areas, Chuitna district, southern Susitna lowland. Modified from Ramsey (1981b).

These major high-angle reverse faults and small-scale, high-angle block faults within the Susitna lowland definitely offset the coal deposits. Most stratigraphic studies of the Cook Inlet petroleum province end at the Castle Mountain fault; however, important coal leases in the Beluga basin lie on both sides of the fault zone. The impact of such faulting on mine development can vary; upthrown blocks, such as in the Chuitna district, provide favorable conditions for extraction of coal (fig. 9), whereas downthrown blocks localize channeling, which leads to erosion of coal seams.

A major structural discontinuity (fig. 10) consisting of the Bruin Bay fault, the Moquawkie magnetic contact, and that part of the Castle Mountain fault east of the Theodore River, divides the Susitna lowland into a deeper southeastern segment, which subsided more rapidly during accumulation of the

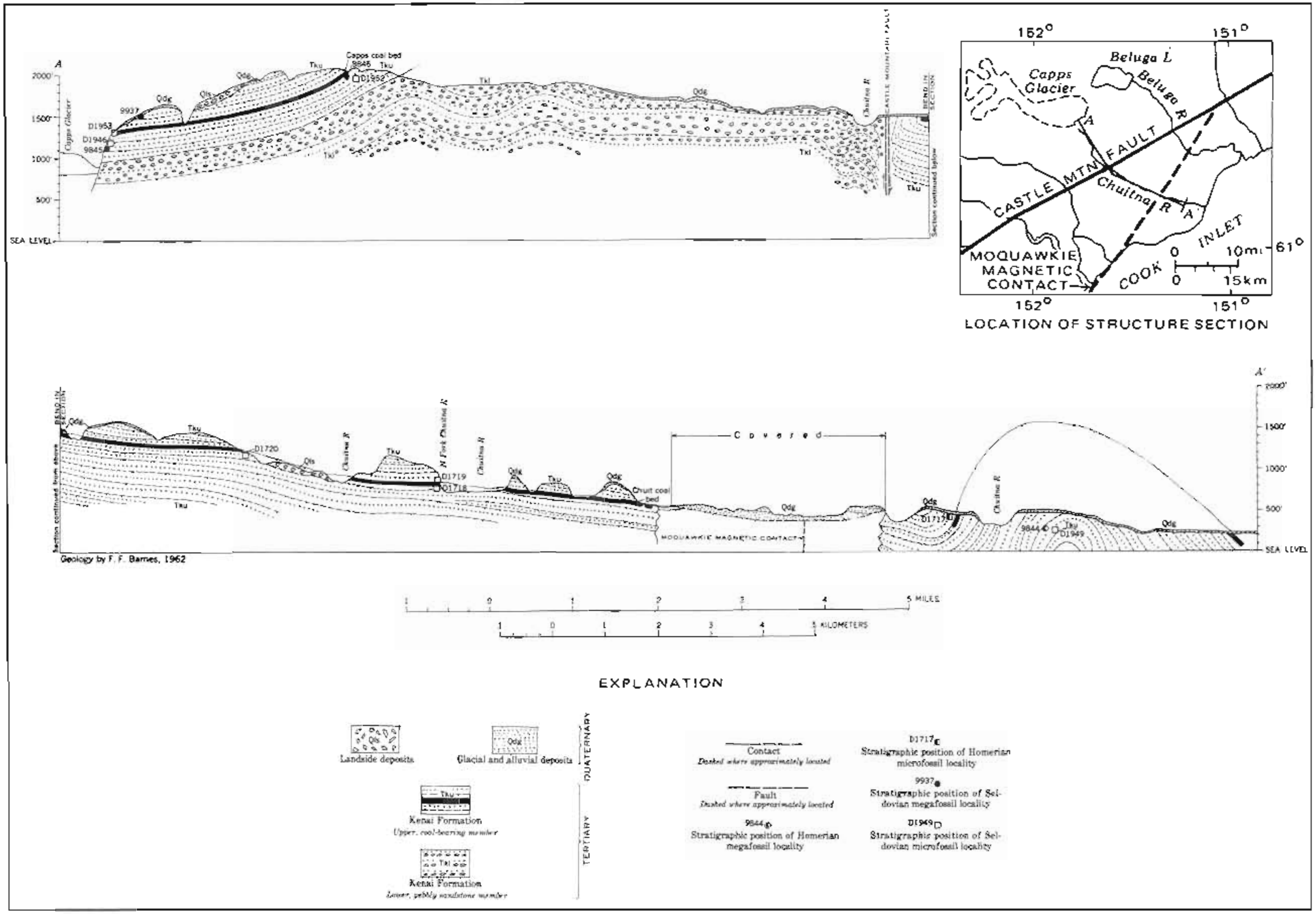


Figure 10. Structure section between Capps Glacier and the lower Chuitna River. From Wolfe and others (1966).

Kenai Group, and a shallower northwestern segment. North of Castle Mountain fault, the Kenai Group is typically <600 m thick, whereas in the southern Susitna lowland it is commonly as thick as 3,000 m (Grantz and others, 1963b; Wolfe and others, 1966; Calderwood and Fackler, 1972; Hartman and others, 1972). Figure 11 shows three generalized cross sections from western Susitna lowland areas. Major faults of the Cook Inlet region have controlled development and configuration of basin depocenters; these thick sedimentary sequences may also contain potential oil-and-gas resources (Hackett, 1976b; fig. 12).

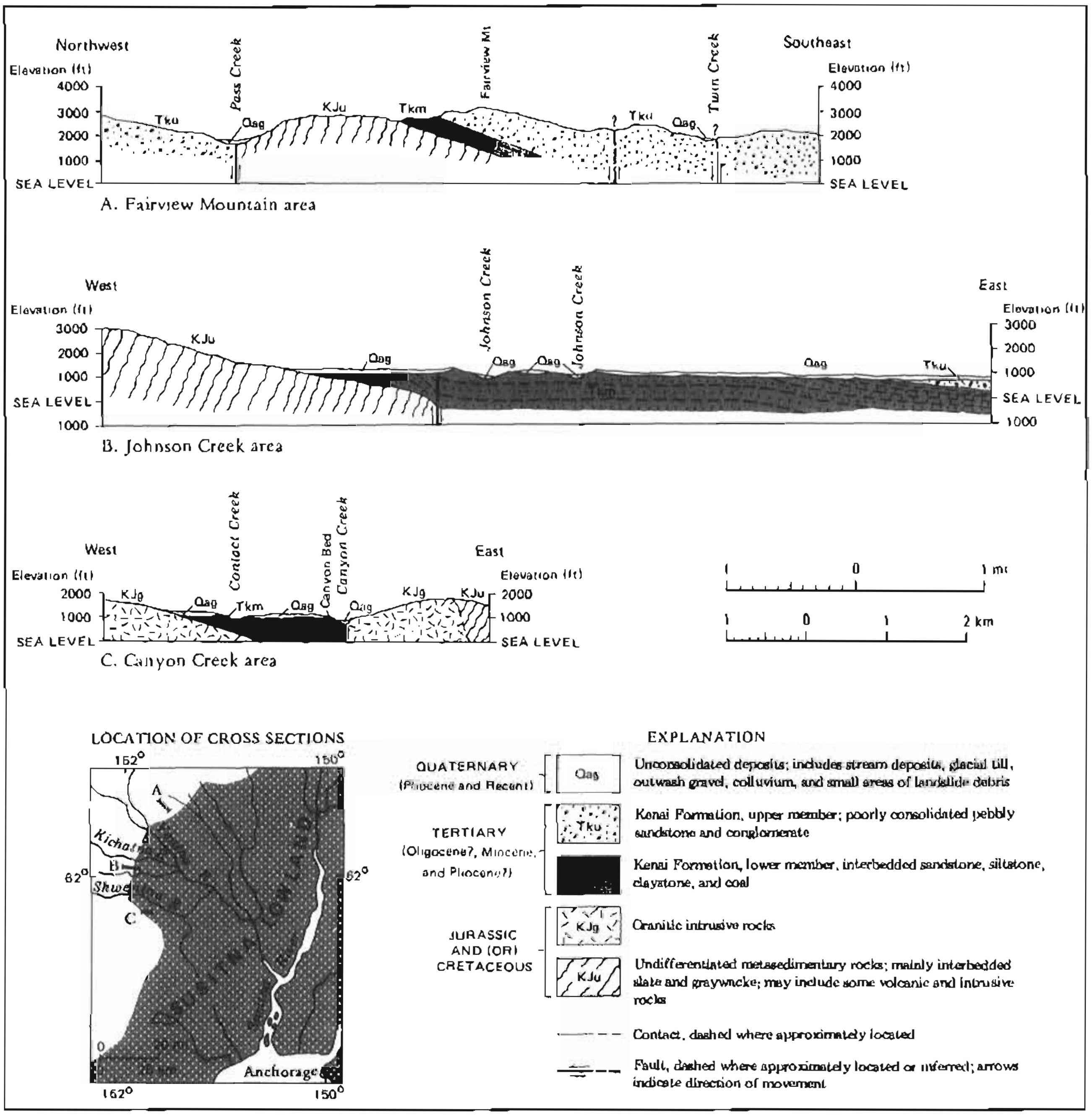


Figure 11. Generalized geologic cross sections of areas along western margin (Fairview Mountain, Johnson Creek, and Canyon Creek) of Susitna lowlands. From Barnes (1966).

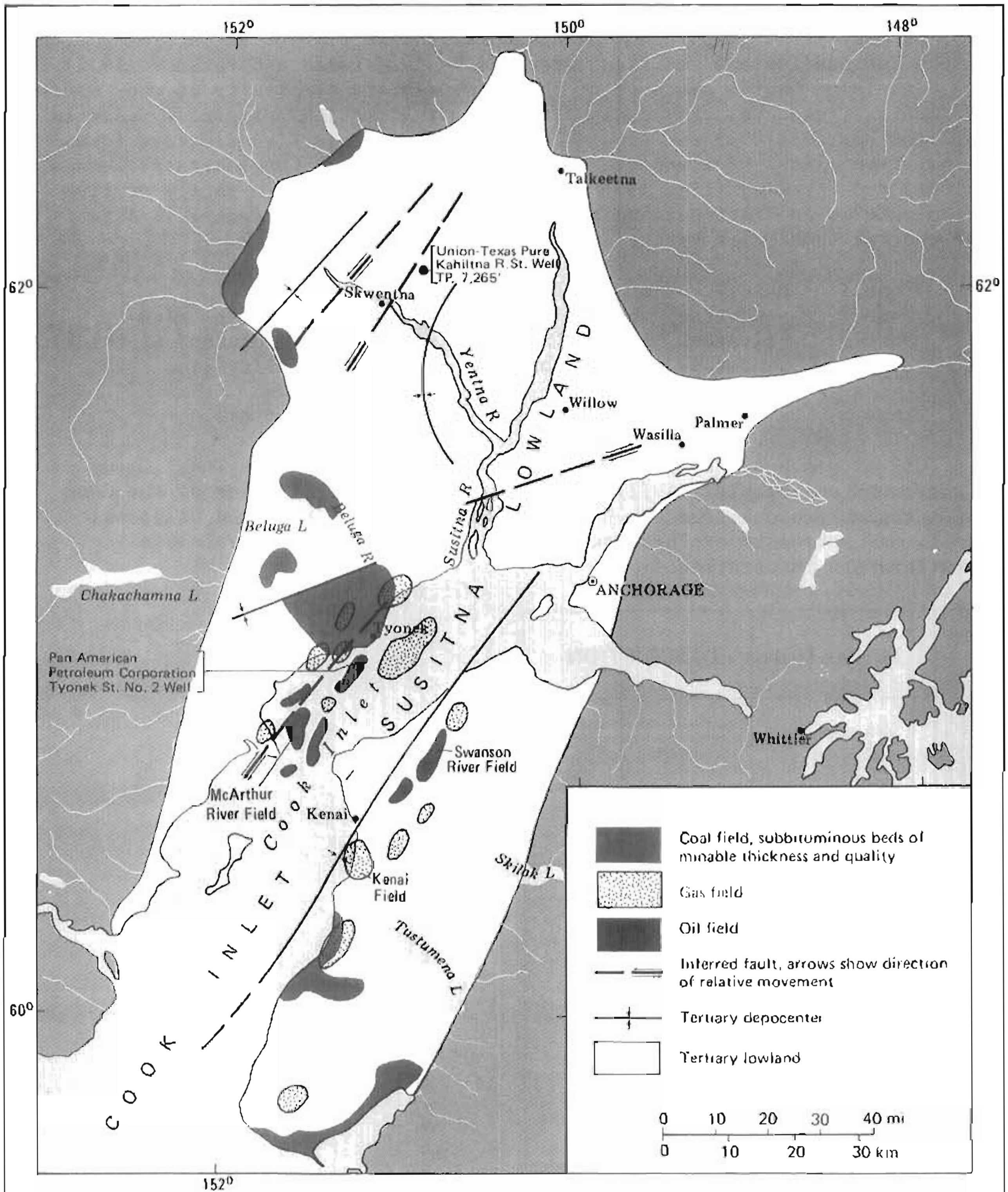


Figure 12. Tertiary depocenters and oil, gas, and coalfields in the Cook Inlet-Susitna lowland area. Modified from Hackett (1976b).

TERTIARY LITHOSTRATIGRAPHY

Current stratigraphic nomenclature for the Tertiary coal-bearing strata of the Susitna lowland was first proposed by Calderwood and Fackler (1972) for the Cook Inlet basin. Because of the thickness and complexity of the Tertiary sedimentary sequence, they changed the 'Kenai Formation' originally adopted by Dall and Harris (1892) to 'Kenai Group' and recognized five distinct formations, from oldest to youngest: West Foreland, Hemlock Conglomerate, Tyonek, Beluga, and Sterling (fig. 13). Their divisions were based partly on five lithologic zones distinguished by Kelly (1963) from subsurface-well data in the central Cook Inlet basin:

Zone 1	massive sand beds (5,000 ft thick)
Zone 2	sandstone, shale, lignite (several thousand ft thick)
Zone 3	siltstone, shale, low-rank coal (several thousand ft thick)
Zone 4	sandstone and conglomerate 'Hemlock producing zone' (700 ft thick)
Zone 5	siltstone and shale (several hundred ft thick).

Oil or gas has been produced from all formations of the Kenai Group (Calderwood and Fackler, 1972), although most major oil fields of the Cook Inlet region produce from the Hemlock Conglomerate (Magoon and Claypool, 1981), and petroleum exploration in this region has yielded valuable stratigraphic information.

SYSTEM	SERIES	GROUP	FORMATION	DESCRIPTION
CENOZOIC	QUATERNARY		Alluvium and glacial deposits	Massive sandstone and conglomerate beds with occasional thin lignite beds
	TERTIARY	KENAI GROUP	Sterling Formation	Claystone, siltstone, and thin sandstone beds, thin, subbituminous coal beds
			Beluga Formation	Claystone, siltstone, and thin sandstone beds; thin subbituminous coals beds
			Tyonek Formation	Sandstone, claystone, and siltstone interbeds and massive subbituminous coal beds
			Hemlock Conglomerate	Sandstone and conglomerate
			West Foreland Formation	Tuffaceous siltstone and claystone, scattered sand stone and conglomerate beds
		Rests unconformably on older Tertiary, Cretaceous, and Jurassic rocks		

Figure 13. General stratigraphic nomenclature for the Tertiary Kenai Group of southcentral Alaska. From Calderwood and Fackler (1972).

Magoon and others (1976) and Boss and others (1978) segregated the West Foreland Formation from the Kenai Group because of the major unconformity separating it from the overlying Hemlock Conglomerate. They regard the Hemlock Conglomerate, not the West Foreland Formation, as the basal formation of the Kenai Group. Boss and others (1978) considered the Hemlock Conglomerate to be a member of the Tyonek Formation; Magoon and others (1976) included it with the Tyonek Formation in their regional compilation (Schmoll and others, 1981).

Barnes (1966) divided the 'Kenai Formation' into lower, middle, and upper members; his coal-bearing middle member contains sandstone, siltstone, claystone, and conglomerate, and the enclosing upper and lower stratigraphic units consist predominantly of pebbly sandstone and conglomerate. Magoon and others (1976) and Reed and Nelson (1980) tentatively correlated equivalent formations between their 'Kenai Group' and the 'Kenai Formation,' basing their work on paleobotanical and palynological studies of Wolfe and others (1966) and on the stratigraphic studies of Calderwood and Fackler (1972). In table 1 Barnes's correlations are compared with those of Magoon and others and Reed and Nelson.

The Kenai Group represents clastic fore-arc-basin deposits of early and late Cenozoic tectonic cycles (Fisher and Magoon, 1978; Schmoll and others, 1981). The rocks are characteristic of a continental fluvial system: they are nondeltaic, except for local lacustrine deltas, and appear to be products of a meandering fluvial regime (particularly in the Tyonek Formation). Lateral migration produced fining-upward sequences, and rapid lateral and vertical changes in lithology are common. Channel deposits are characteristically coarse-grained sediment; fine-grained rooted siltstone, shale, and thin coal represent interfluve sediments. Levees that flank channels are typically fine-grained sandstone and siltstone. Sedimentary structures other than cross-stratification in coarser grained units are rare on natural exposures.

The coals and enclosing strata of the Susitna lowland also are characteristic of freshwater paleoenvironments. These sedimentary sequences can be differentiated from marine and brackish-water systems by the following primary characteristics:

. moderate to high ash content in coals--represents influxes of terrigenous silt (ash typically low in pyrite and carbonate minerals and high in quartz and kaolinite)
. locally thick coals, but discontinuous laterally
. low sulfur in coals and overburden
. lack of diagnostic marine fossils--absence of faunal elements and burrowing (biogenic structures; bioturbation)
. high sand-to-mud ratios of associated rocks
. abundant organic matter and plant detritus of associated rocks; common coalified roots and in-place stumps
. rare dark-gray to black claystone
. frequent rooted, slickensided, refractory underclays
. illitic-kaolinitic clay associations
. siderite nodules and bands present in coals and associated strata, but not common or diagnostic--presence reflects poor drainage.

Tertiary sedimentary rocks of the Susitna lowland north of the Castle Mountain fault are relatively thin--typically 600 m or less, but with three depocenters over 1,500 m thick (fig. 14)--and they nonconformably overlie

Table 1. *Tentative correlations of geologic units.*

Area	Barnes (1966): Kenai Formation Member	Magoon and others (1976): Kenai Group Formation
	Tyonek Quadrangle	
1. South of Capps Glacier	a. Lower b. Middle	a. West Foreland b. Tyonek
2. North of Lone Ridge	Lower	West Foreland
3. Beluga River		
a. North of Lake Clark fault	a. Lower	a. West Foreland
b. Between Lake Clark and Bruin Bay faults	b. Middle	b. Tyonek
c. South of Bruin Bay fault	c. Middle	c. Beluga
4. Chuitna River between Lake Clark and Bruin Bay faults	Middle	Tyonek
5. Tributaries of Nikolai Creek south of Lake Clark fault	Lower	Tyonek
6. Threemile River-Lewis River area south of Little Mt. Susitna and north of Lake Clark fault	Lower	West Foreland
7. Drill Creek and Coal Creek	Middle	Tyonek
8. Talachulitna River; Friday and Saturday Creeks	Middle	Tyonek
9. Canyon Creek	Middle	Tyonek
10. Skwentna River northeast of Porcupine Butte	Middle	Tyonek
11. Kahiltna River north of confluence with Yentna River	Middle	Tyonek

Area	Barnes (1966): Kenai Formation Member	Reed and Nelson (1980): Kenai Group Formation
	Talkeetna Quadrangle	
12. Johnson Creek	a. Middle b. Upper	a. Sandstone Member of Tyonek b. Sterling
13. Kichatna River	Upper	Sandstone Member of Tyonek or Sterling
14. Nakochna River	a. Middle b. Upper	a. Conglomerate Member of Tyonek b. Sterling
15. Yenlo Creek, Lake Creek, and Kahiltna River northwest of Shulin Lake	Middle	Sandstone Member of Tyonek
16. Bear Creek east of Little Peters Hills	Middle	Sandstone Member of Tyonek
17. Drainages southeast of Peters Hills	Middle	Sandstone Member of Tyonek
18. Cache Creek	Middle	Sandstone Member of Tyonek or Sterling
19. Dollar Creek	Middle	Sterling
20. Long Creek-Cottonwood Creek	Middle	Sterling
21. Tributaries of Long Creek-Cottonwood Creek northwest of Peters Hills and Willow, Poorman, Pass, and Divide Creeks	Upper	Sterling
22. Treasure Creek east of Chelatna Lake	Upper	Sterling
23. Fairview Mtn. and region south of Mt. Kliskon	Upper	Sterling
24. Cottonwood Creek	Middle	Conglomerate Member of Tyonek
25. Sunflower Creek	Middle	Sterling
26. Bluff Creek, southwest margin of Ruth Glacier	Upper	Conglomerate Member of Tyonek or Sterling

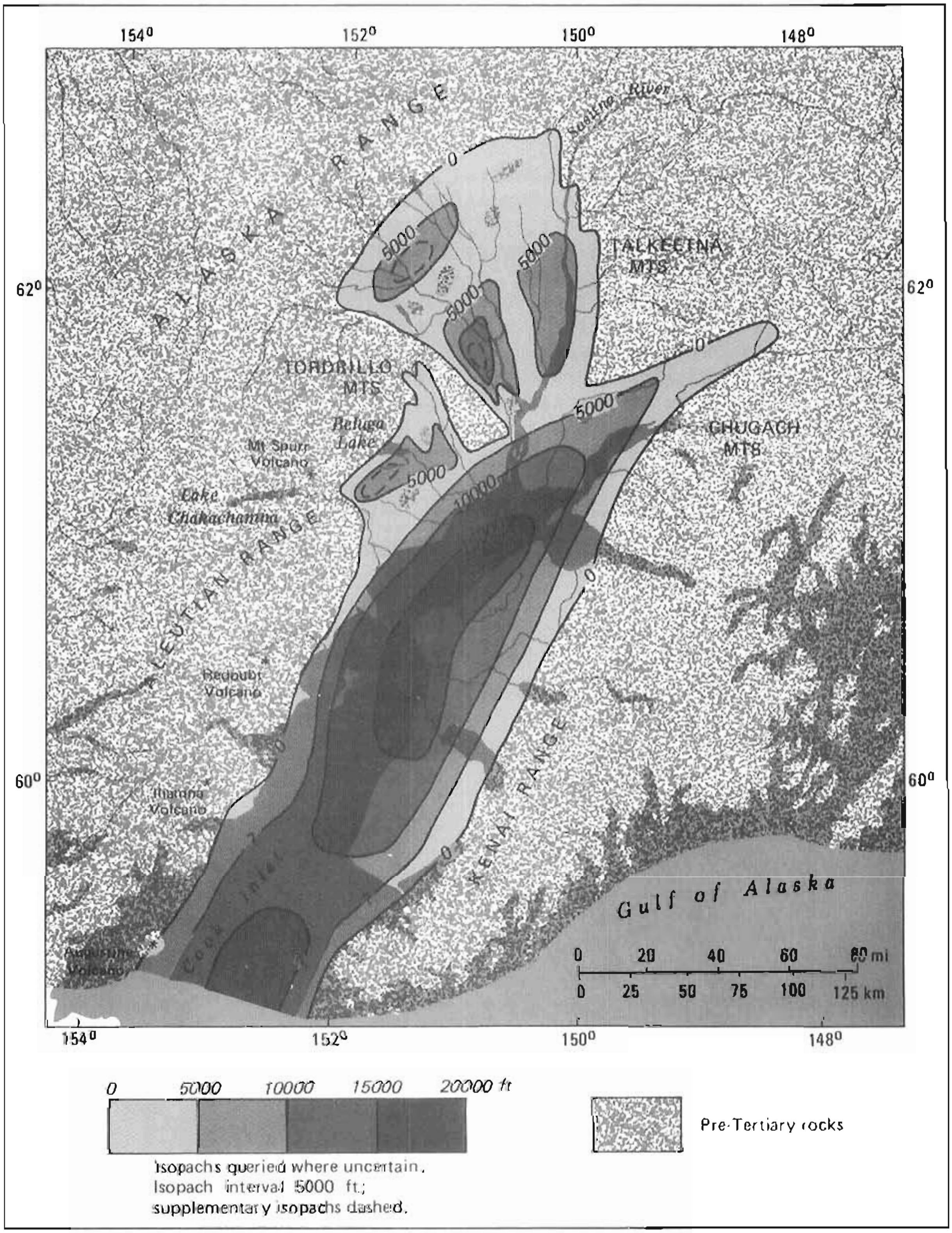


Figure 14. Generalized isopach map of Tertiary deposits in the Cook Inlet-Susitna lowland area. Modified from Kirschner and Lyon (1973), Hartman and others (1972), and Hackett (1977).

granitic rocks. The Kenai Group ranges to over 3,000 m thick, but is commonly <1,500 m thick south of the Castle Mountain fault in the southern Susitna lowland; in this region, it usually overlies older Tertiary and Mesozoic sedimentary rocks. In the central part of the Cook Inlet basin, the group is more than 4,500 m thick (Kirschner and Lyon, 1973; Hartman and others, 1974).

Kenai Group sediments in the Susitna lowland derived mainly from plutonic and metamorphic sources in the tectonically active Alaska Range and Talkeetna Mountains. Kirschner and Lyon's (1973) model portrays a broad intermontane trough confined by borderlands of low to moderate relief during warm to temperate climatic conditions (fig. 15). They divide deposition of the Kenai Group of the Cook Inlet basin into three phases based on the lithologic and mineralogic character of the sediments: (1) an Oligocene-Miocene transgressive phase; (2) a brief late Miocene culmination (stillstand); and (3) a Pliocene regressive phase. The West Foreland Formation, Hemlock Conglomerate, and lower Tyonek Formation were deposited in the transgressive phase. The late Miocene culmination was characterized by a transitional period of low-energy sedimentation, when the siltstone, carbonaceous shale, and coal in the upper part of the

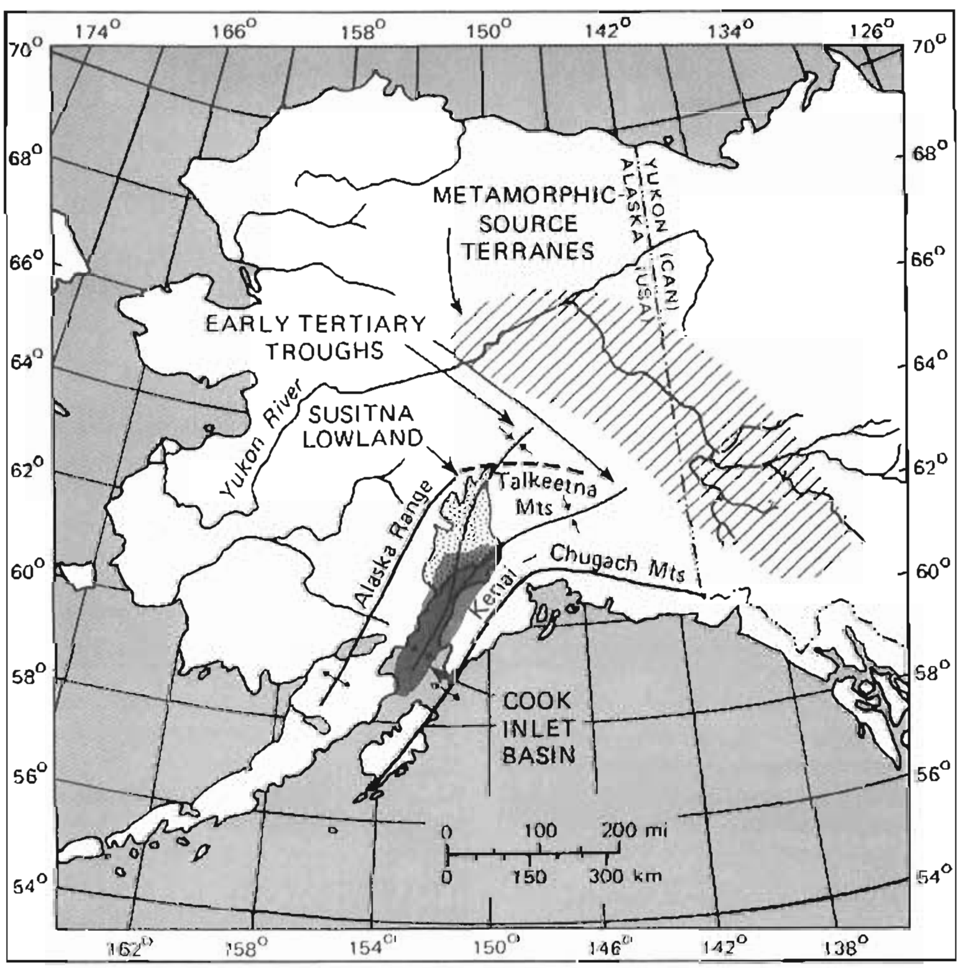


Figure 15. Primary elements of a Tertiary model for the Cook Inlet-Susitna lowland. From Kirschner and Lyon (1973).

Tyonek Formation and the lower part of the Beluga Formation were deposited. All factors related to coal formation, such as plant growth, basin subsidence, sediment supply, compaction, and interaction of the ground-water table, must have been favorable at that time. The upper part of the Beluga Formation and the Sterling Formation were deposited during the Pliocene regressive phase.

Exposures of the Kenai Group are confined to the basin rim (foothills of the Alaska Range) and isolated, usually steep walls of incised and largely inaccessible stream canyons in the lowlands. Minor outcrops of Tertiary rock also occur along coastal areas such as Beshta Bay (fig. 16). Tertiary deposits are usually overlain by Pleistocene glacial drift or stream alluvium that veils the underlying material. The contact between Tertiary and Quaternary deposits is often obscured by deep weathering or buried. Outcrops of coal-bearing deposits are widely distributed but discontinuous and highly weathered (sheet 1 and app. A, tables A-1 through A-3); spatial relationships are therefore difficult to observe. Without essential subsurface control, horizontal migration of individual facies cannot be documented.

Logs are available from several oil wells in the southern Susitna lowland near Cook Inlet (Magoon and others, 1976), and, in the central Susitna lowland a Union-Texas Petroleum well (Pure Kahiltna River State 1) has been drilled. Two drill holes penetrate coal-bearing units in the Capps district (Chleborad and others, 1980, 1982). Core data from several USBM drill holes in the Beluga field (Warfield, 1962) and the gravity data of Hackett (1977) on the southern Susitna lowland constitute the remaining available subsurface data.

In addition to the Kenai Group, five Tertiary or Cretaceous sedimentary formations crop out in the southeastern part of the Susitna lowland (sheet 1; table 2). These formations are older than those of the Kenai Group (fig. 17), except for the Tsadaka Formation, which is approximately time equivalent to

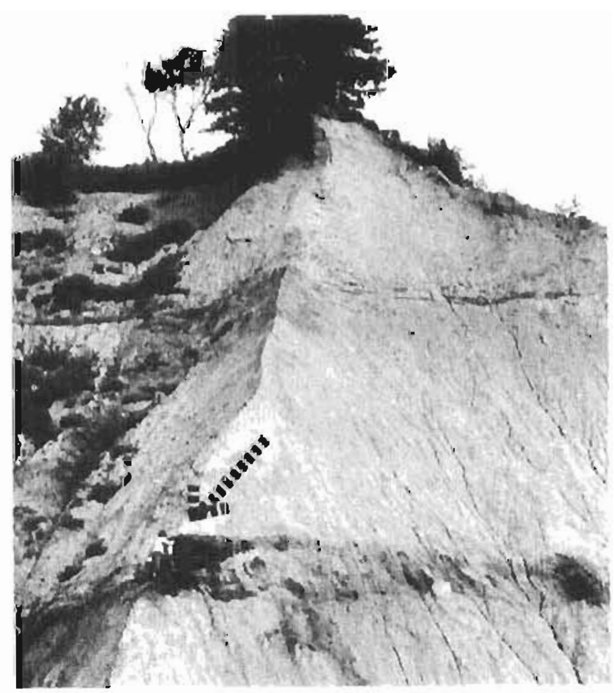


Figure 16. Coal-bearing Tertiary sedimentary rocks (Beluga Formation) exposed along a 15-km outcrop at Beshta Bay, Cook Inlet. Photograph by J.E. Sperber, 1981.

Table 2. *Summary of chief characteristics of Tertiary and Cretaceous sedimentary rock formations of the Little Susitna district (southeastern Susitna Lowland) and lower Matanuska Valley (modified from Clardy, 1978).*

Formation	Age	Thickness	Lithology	Stratigraphic relationship	Depositional environment
Tsadaka	Oligocene; time equivalent of lowest beds of Kenai Group	Over 150 m in Tsadaka Canyon	Crudely stratified, massive conglomerate; marginal conglomeratic facies of Kenai Group	Overlies Wishbone and Chickaloon Formations with a distinct angular unconformity in lower Matanuska Valley	Sheet-flood debris deposited on alluvial fans
Wishbone	Eocene	550-600 m	Well-lithified conglomerates, sandstones, and siltstones	Unconformably overlies Chickaloon Formation in Matanuska Valley	Fluvial environment; alluvial fans and associated braided streams, perhaps meandering stream deposits in part
Chickaloon	Paleocene	At least 1,500 m thick in Matanuska Valley	Well-indurated claystones, siltstones, sandstones, conglomerates, coal	Conformable with overlying Wishbone Formation south of Willow Creek in southwestern Talkeetna Mountains	Fluvial, braided to meandering stream environment in lower part; fluvial meandering to paludal environment in upper part
Arkose Ridge	Paleocene	Unknown	Coarse-grained clastics (arkosic conglomerates, minor shales)	Nonconformably overlies plutonic rocks along south flank of Talkeetna Mountains and overlies Talkeetna Formation to northeast	Local source, fanglomerate deposit
Matanuska	Early to Late Cretaceous (Albian to Maestrichtian).	Over 1,200 m thick at type section in Matanuska Valley.	Siltstones, sandstones, and cobble conglomerates.	Underlies Tertiary rocks with local disconformity.	Marine; sublittoral to outer bathyal or abyssal deposition by density currents or submarine slumps.

the lowest beds of the Kenai Group. The Chickaloon Formation is the only coal-bearing unit in this area.

West Foreland Formation

The West Foreland Formation crops out in the southern foothills of the Alaska Range. In the Beluga field, exposures occur northwest of the Lake Clark and Castle Mountain faults. In the Capps district, Adkison and others (1975) measured 630 m of West Foreland Formation strata in exposed sections. The type section for the West Foreland Formation is a drill hole 60 km south of the Capps district; at the type locality, the unit is 270 m thick (Kelly, 1963).

The West Foreland Formation is the lone representative of the early Cenozoic tectonic cycle. It was deposited on an erosional surface of Mesozoic and early Tertiary rocks and is composed of interbedded siltstone, tuffaceous claystone, graywacke, and poorly sorted polymictic conglomerate with a few thin lignitic coal beds (Schmoll and others, 1981).

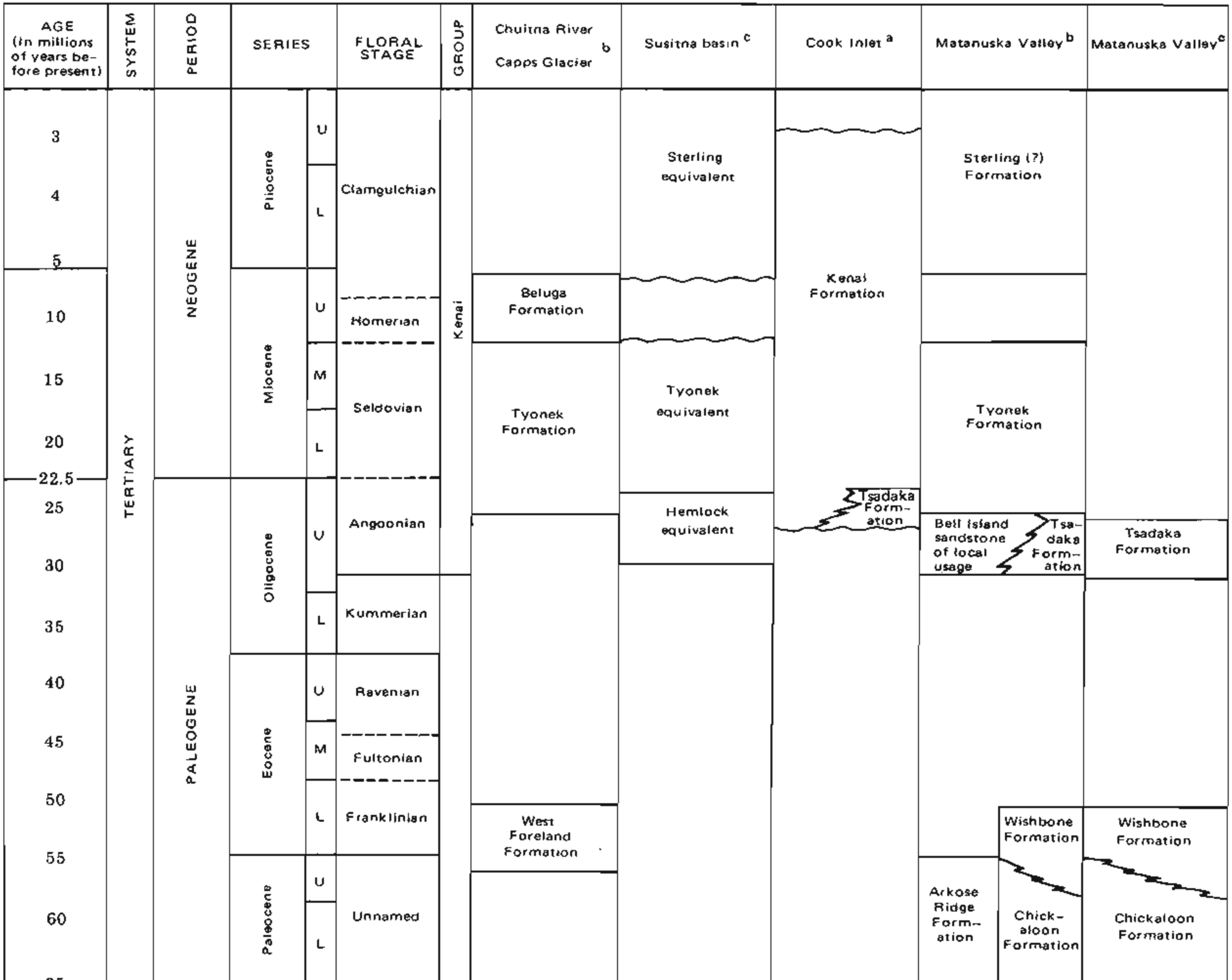


Figure 17. Surface and subsurface Tertiary stratigraphy of five coal-bearing regions in southcentral Alaska. From Wolfe and others (1966)[a]; Magoon and others (1976)[b]; Conwell and others (1982)[c].

Hemlock Conglomerate

The Hemlock Conglomerate has been mapped northwest of the Castle Mountain fault (Detterman and others, 1976b); Magoon and others (1976) restrict it to the southeast side of the Bruin Bay fault. Calderwood and Fackler (1972) found it in the subsurface in the Beluga area. The unit is predominantly pebbly sandstone and conglomerate with minor siltstone. The conglomerate contains white quartz and black chert clasts (Conwell and others, 1982). Thought to be early Oligocene and assigned to the Angoonian stage by Wolfe (1977), the Hemlock Conglomerate forms the basal unit of the late Cenozoic tectonic cycle in the refined classification of the Kenai Group (Boss and others, 1978; Schmoll and others, 1981); the unit contains no significant coal deposits.

Tyonek Formation

The type section for the Tyonek Formation (Calderwood and Fackler, 1972; Sanders, 1981) is in the Pan American Petroleum Corporation Tyonek State 2 well which penetrated 2,272 m of Tyonek Formation and intersected 42 significantly thick coal beds (fig. 18). Adkison and others (1975) described exposures of the lower Tyonek Formation south of Capps Glacier, including the Capps and Waterfall coal beds (figs. 19 and 20), and assigned coal-bearing exposures along the Chuitna River to the upper part of the Tyonek Formation. The formation underlies most of the Beluga field southeast of the Lake Clark and Castle Mountain faults. Outcrops around Capps Glacier and along the Chuitna River serve as the type section for the Seldovian Stage (Wolfe and others, 1966; Wolfe, 1977).

The Tyonek Formation is generally finer grained than the West Foreland Formation and Hemlock Conglomerate. The unit contains the thickest coal beds of the Kenai Group. Other lithologies present are massively bedded sandstone, siltstone, claystone, and conglomerate. Adkison and others (1975) divided the Tyonek Formation in the Chuitna district into a basal conglomerate, the Middle Ground Shoals Member, and a finer grained upper coal-bearing unit, the Chuitna Member, which corresponds to the upper part of the lower Kenai Formation of Barnes (1966). In the Pan American Petroleum Chuitna River State 1 well, the Middle Ground Shoals Member occupies the interval from 562 to 1,894 m (Ramsey, 1981b). Adkison and others (1975) noted the absence of the Hemlock Conglomerate and the West Foreland Formation in the Pan American well, and stated that the Middle Ground Shoals Member rested on the Chickaloon Formation.

The Chuitna Member of the Tyonek Formation crops out in Chuitna River Canyon (fig. 21) and correlates with the Kenai Formation of Barnes (1966). The Chuitna Member comprises about the upper 565 m in the Pan American well. The stratigraphically highest coal bed in the well, the Brown Seam (Ramsey, 1981b), probably corresponds to the Chuitna bed of Barnes (1966) and is underlain by five other beds (from highest to lowest): the Yellow, Green, Blue, Orange, and Red seams.

Reed and Nelson (1980) divided the Tyonek Formation in the Talkeetna Quadrangle into the Sandstone and Conglomerate Members. The Sandstone Member either is conformable with or interfingers with the underlying Conglomerate Member. The Tyonek Formation is separated from Mesozoic rocks by an angular unconformity. The Sterling Formation, stratigraphically the highest unit of

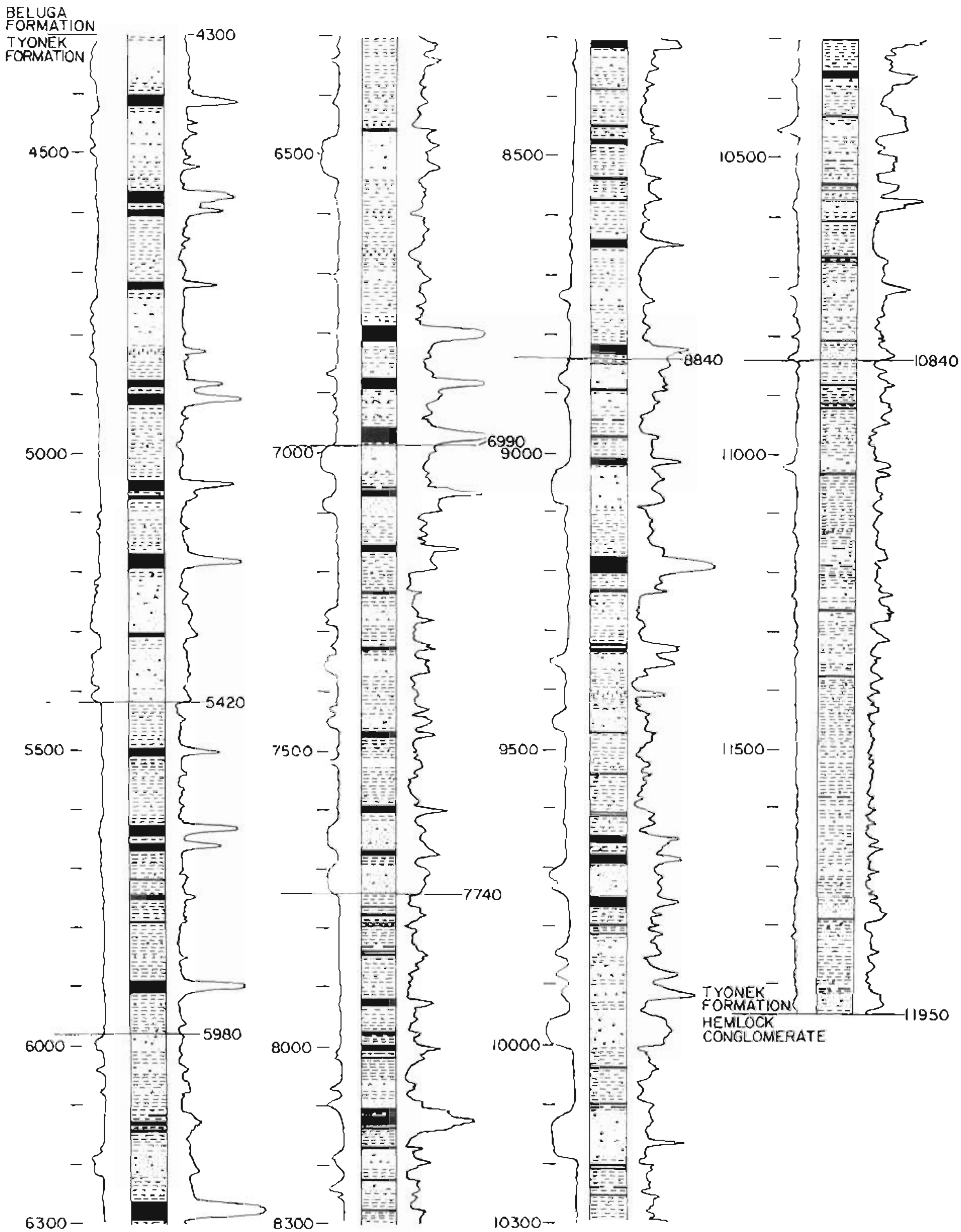


Figure 18. Lithologic and geophysical logs of the type section of the Tyonek Formation (Pan American Petroleum Corporation Tyonek State 2 well east of Granite Point, Cook Inlet). From Calderwood and Fackler (1972).

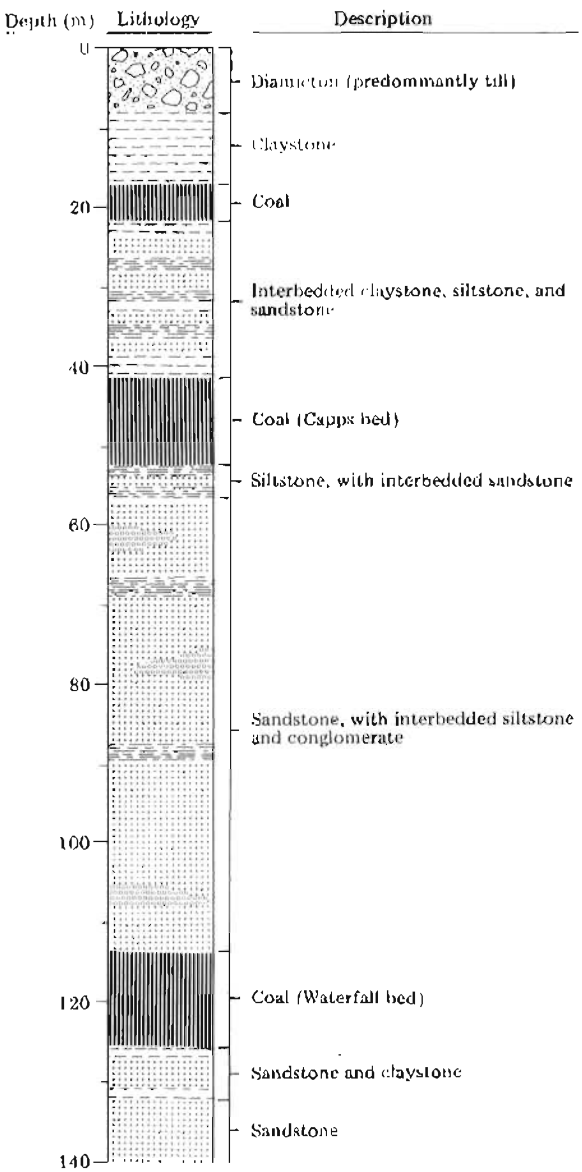


Figure 19. Generalized lithologic log from a test hole near Capps Glacier showing stratigraphic positions of the Capps and Waterfall coal beds (Tyonek Formation). From Chleborad and others (1980).

the Kenai Group, unconformably overlies the Tyonek Formation, as suggested by the presence within it of coal fragments derived from the Tyonek Formation. The beds of the Sandstone and Conglomerate Members consistently dip gently or moderately to the southeast.

The Sandstone Member is dominantly (to 80 percent) sandstone, typically medium to coarse grained, pebbly, and poorly indurated. Reed and Nelson (1980) reported sandstone beds as thick as 60 m at Fairview Mountain. Mineralogically, the sandstone is composed of about 75-85 percent chert and quartz grains, 10-20 percent feldspar, and about 5 percent mafic grains (biotite, hornblende, clinozoisite, and chlorite). Interbedded siltstone and claystone make up 20 percent of the Sandstone Member and are commonly light to medium gray, rooted,

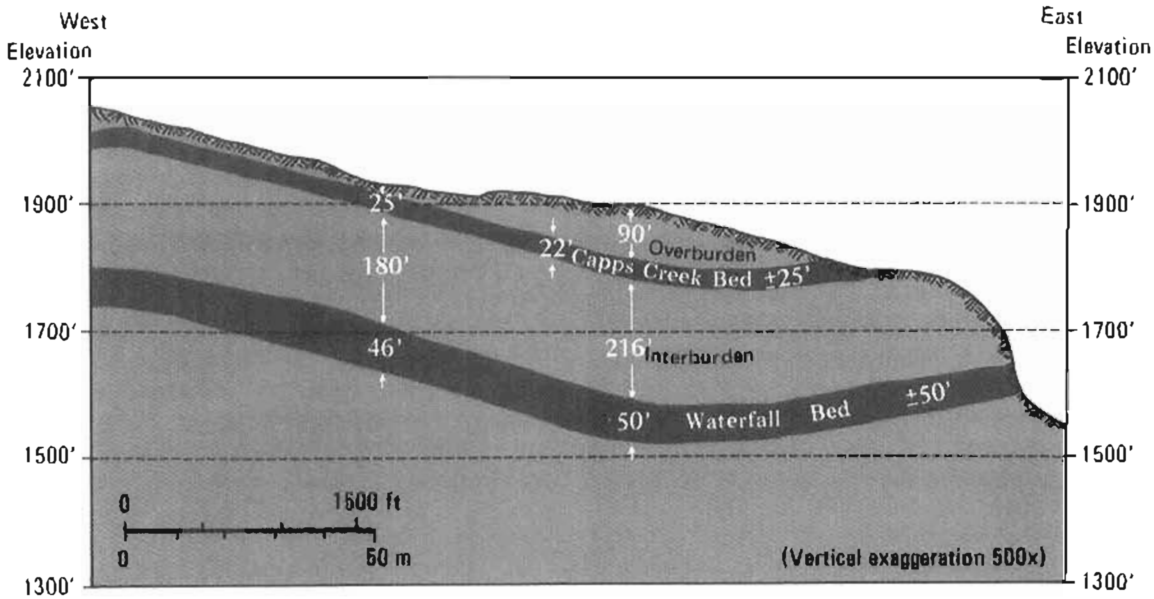


Figure 20. Generalized cross section of the Beluga coalfield in the Capps district showing thicknesses of the Capps and Waterfall beds, including overburden and interburden zones. Modified from Conwell (1977b).

and locally include coal stringers; they attain thicknesses to 50 m. Conglomerate, coal, and volcanic ash compose <1 percent of the Sandstone Member. The conglomerate occurs in beds to 5 m thick, with incorporated clasts that range to 10 cm diam, but average 2-6 cm diam. The coals occur within fining-upward (conglomerate-sandstone-siltstone-claystone-coal) cyclic sequences, often include carbonaceous shale or bone partings, and average <1 m thick; however, they attain thicknesses of 3 m within the Sandstone Member.

Volcanic-ash partings within the coal beds may be as thick as 30 cm and consist of partially devitrified glass shards that have altered to illite(?), with <0.5 percent biotite (Reed and Nelson, 1980). These ash partings often contain fossil roots and indicate that volcanic activity was contemporaneous with coal and sediment deposition.

The Conglomerate Member is generally light brown to blue gray, massively bedded, poorly indurated, and consists of 40 percent conglomerate, 20 percent sandstone, and <40 percent siltstone, claystone, and coal. Clasts of the petromictic conglomerate ranged to 15 cm diam but averaged 5-10 cm diam. Proportions of different lithologies vary; quartz and chert clasts are most abundant at Nakochna River; igneous-rock clasts predominate at Fairview Mountain. To the northeast from Nakochna River, shale and graywacke clasts increase proportionately to over 90 percent at Ruth Glacier. Grain sizes in the sedimentary rocks grade upward (coarse to fine) in cyclic units from conglomerate to sandstone, sandy siltstone, silty claystone, and coal. Sandstone lenses are also poorly indurated and typically coarse-grained and pebbly. Coal beds of the Conglomerate Member average 0.6-3.0 m in thickness; four coal beds (<2.2 m

Figure 21. Outcrop of the Chuitna bed (Barnes, 1966; 'Brown Seam' of Ramsey, 1981b) along the Chuitna River (Tyonek Formation, Beluga coalfield). Photograph by J. E. Sperber, 1981.

thick each) are well exposed at Fairview Mountain (fig. 22); one thick (4.5 m exposed) coal bed crops out along Camp Creek. These subbituminous coals are black to brownish black with a dull luster and usually contain claystone, carbonaceous shale, or bone-coal partings. Occurrences of coal within the Fairview Mountain region were first described by Capps (1913). Wolfe and others (1966) determined that an outcrop at Chicago Gulch was Seldovian (lower to middle Miocene).

The Tyonek Formation is late Oligocene to middle Miocene. Triplehorn and others (1977) obtained an age of 15.8 Ma from a volcanic-ash parting in a coal bed of the upper Seldovian section of the Tyonek Formation along the Chuitna River. Time-stratigraphic markers, such as volcanic-ash partings, are rare in the Susitna lowland. The geochemistry of an ash parting from the Capps bed (fig. 23) is consistent with its interpreted origin as an air-fall tuff (Spears and Kanaris-Sotiriou, 1979).

Rocks of the Tyonek Formation are mostly products of channel and floodplain sedimentation. Some coarse-grained components indicate a near-source lithotype. Lacustrine deposits also occur locally.

The Tyonek Formation contains most of the coal resources of the Susitna lowland. The formation is widely distributed over the region, and its coals are generally thicker, more laterally continuous, and of better quality (lower ash contents and higher heating values) than those of the Beluga and Sterling Formations.

Figure 22. Fairview Mountain coal beds (C through F) of the Conglomerate Member of the Tyonek Formation, northwest Susitna lowland. Photograph by J.E. Sperber, 1981.

Beluga Formation

The Beluga Formation crops out along the lower Beluga and Chuitna Rivers and along Beshta Bay east of Granite Point (sheet 1). Total thickness of the Beluga Formation cannot be determined from outcrops, but it is more than 1,200 m thick in the type section, a well near Beluga (Schmoll and others, 1981). The coal sequence within the formation dips eastward beneath Cook Inlet and extends into the subsurface of the Kenai Peninsula (Sanders, 1981). The formation consists of thin-bedded sandstones, claystones, and local lignitic coals with bentonitic claystone interbeds; near basin margins, the formation grades into predominantly sandy siltstones, claystones, and bony coals. The unit is late Miocene and is assigned to the Homerian Stage and lower part of the Clamgulchian Stage (Wolfe, 1966).

The large proportion of graywacke and greenstone lithic fragments in pebbly sandstone and conglomerate beds of the Beluga Formation suggests that these sediments may have been shed from the south and east during uplift of the Chugach Range; a secondary source area may be the Alaska Range to the north. The sediments were probably deposited as coalescing alluvial fans on fluvial plains (Clardy, 1978) from source areas of moderate to low relief.

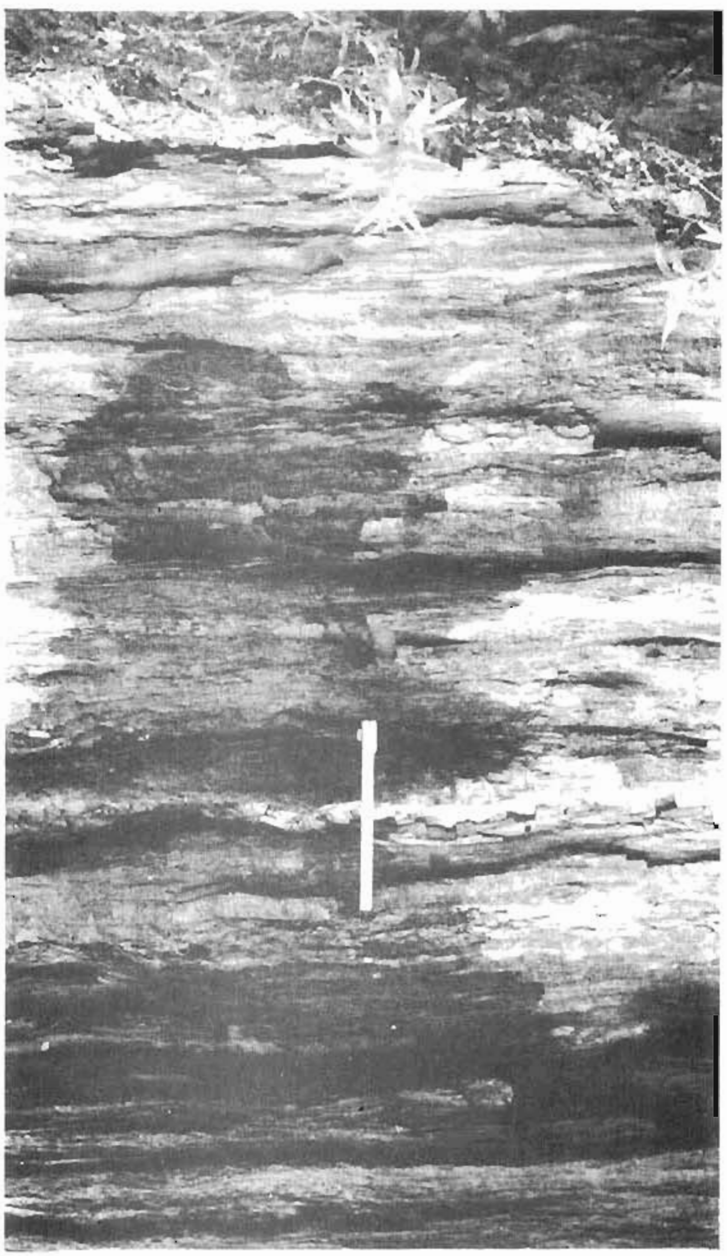


Figure 23. Volcanic-ash partings in the Capps bed of the Tyonek Formation, Beluga coalfield. Photo by J.E. Sperber, 1981.

In the Susitna Lowland, the Beluga Formation covers a much smaller area and contains considerably less coal than the Tyonek Formation; additionally, the quality of Beluga Formation coals is considerably lower.

Sterling Formation

Sterling Formation strata were mapped by Reed and Nelson (1980) in the northern Yentna basin (sheet 1). At Fairview Mountain, the unit is 770 m thick. In the Beluga well, the unit overlies the Beluga Formation and, with Quaternary deposits, makes up the upper 1,100 m of strata (Kelly, 1963). In the Yentna basin, the Sterling Formation is a predominantly sandy, loosely consolidated unit with minor claystone and a few relatively thin (2-m-thick) lignitic coals. Reed and Nelson (1980) described it as an orange to light-gray massive conglomerate with coarse-grained clastics. Clast diameters range to 30 cm but average 5-10 cm diam. Induration is typically poor to moderate with a clay or iron oxide (ferruginous) matrix. Clast lithologies are the same as in the Tyonek Formation (quartz, chert, shale, graywacke, and igneous rocks) but occur in different proportions.

The Sterling Formation is late Miocene and Pliocene and falls within the Clamgulchian Stage of Wolfe (1966). Triplehorn and others (1977) obtained K-Ar ages ranging from 6 to 11 Ma from volcanic-ash partings within coal beds of the Sterling Formation on the Kenai Peninsula. Sterling Formation deposits are probably characteristic of braided streams that drained a tectonically active area (Clardy, 1978). Near basin margins, the formation becomes conglomeratic, indicating a high-energy environment, near the source. Epidote dominates the heavy-mineral suite (Kirschner and Lyon, 1973). An indication of provenance is the east-to-southeast current directions displayed in cross-bedded sandstone lenses.

Coal deposits of the Sterling Formation are of minor significance compared with those of the Tyonek Formation. In the Susitna lowland, Sterling Formation coals of the northern Yentna basin are discontinuous and generally of low quality.

PALEOBOTANY AND PALYNOLOGY

The ages of Tertiary coal-bearing stratigraphic units in southcentral Alaska were established by the paleobotanical and palynological work of Wolfe and others (1966) who proposed three new provincial chronostratigraphic units: the Seldovian, Homerian, and Clamgulchian Stages. Plant megafossils and microfossils (spores and pollens) were the criteria for age assignments (fig. 24). No megafossil or microfossil plants of Clamgulchian age have been found in the Susitna lowland. Adkison and others (1975) measured numerous sections on the south side of Capps Glacier and at two localities along the Chuitna River, and provided detailed lithologic descriptions and lists of identified palynomorph assemblages.

From his study of leaf floras of southwestern British Columbia and other parts of northwestern North America, Wolfe (1978) concluded that middle Eocene time was characterized by widespread equable climates. The warm and temperate broadleaf forests were no longer dominant after middle Miocene time, and cool temperate floral families such as Betulaceae (birch) proliferated (Wolfe, 1972, 1977; Wolfe and others, 1980).

Williams and Ross (1979) also postulated a period of widespread equable climates in their study of Eocene coal-bearing strata in the Tulameen coalfield of southcentral British Columbia. This type of climate is inferred in most Tertiary models (Kirschner and Lyon, 1973) and likely was characteristic of the period during deposition of the coal-bearing Tyonek Formation in the Kenai Group. The relatively lush plant growth of a lowland-plain paleoenvironment would account for formation of the thick peats and (ultimately) thick coals of the Tyonek Formation.

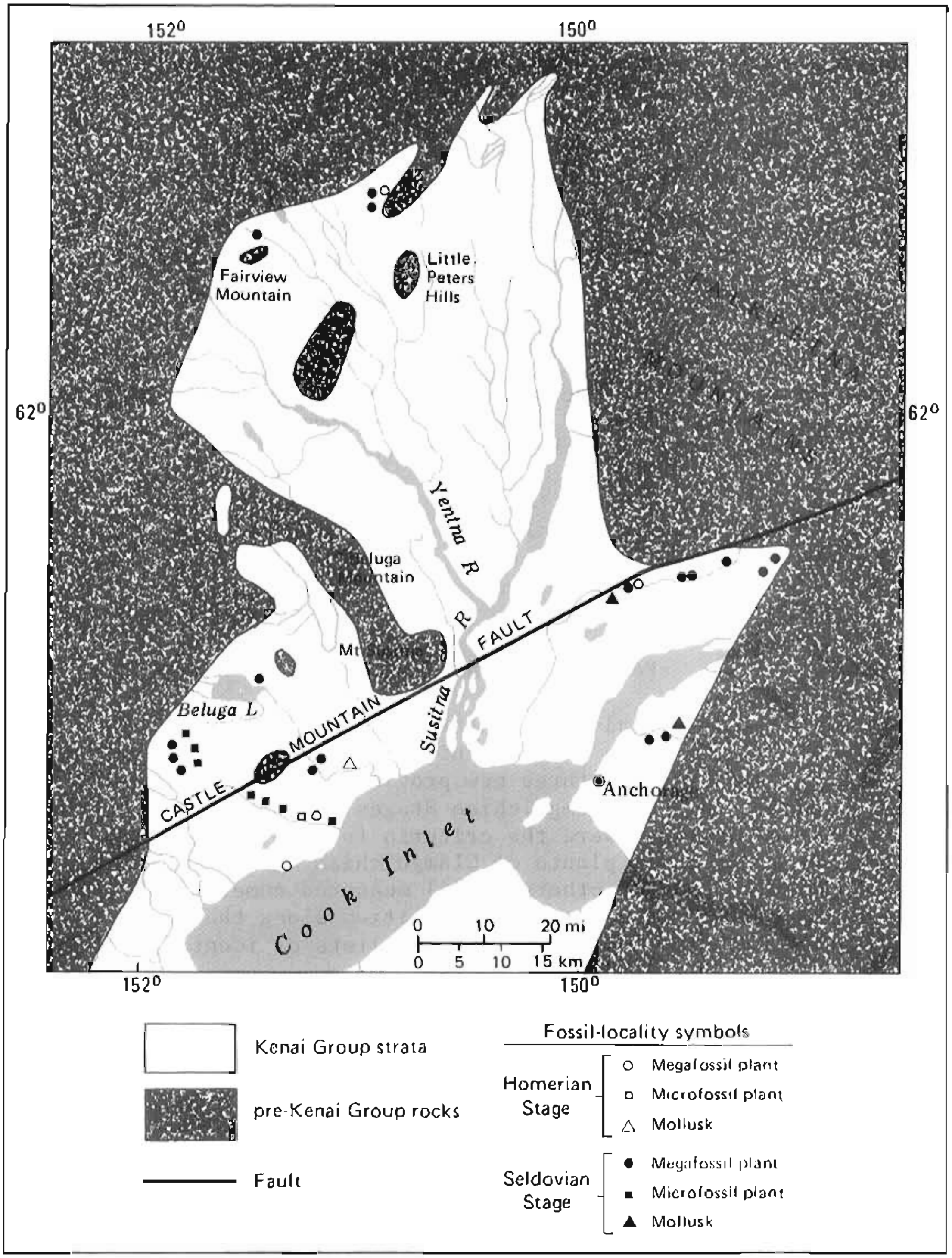


Figure 24. Seldovian and Homerian Stage fossil localities in the Susitna lowland. Modified from Wolfe and others (1966).

PETROGRAPHY OF TYONEK FORMATION ROCKS

Sandstones

Composition

Sandstones of the Tyonek Formation examined during this study (sample locations on pl. 1; descriptions in app. C) were predominantly medium grained and varied from gray to brown, locally slightly tinted green or blue. Graded bedding was common, and fining-upward sequences were transitional from coarse-grained sandstone at the base to fine-grained sandstone and siltstone upsection. Sandstones consisted predominantly of quartz and rock fragments in an argillaceous matrix or cemented by silica. Feldspar, mica, and heavy minerals were minor accessory components.

Quartz grains ranged from silt to pebble size. Plutonic (with vacuoles) exhibiting strain shadows and vein quartz exhibiting slight to strong undulatory extinction were most abundant. Minor quartz probably originated from metamorphic rocks; a few polycrystalline or mosaic grains were also observed.

Rock fragments were usually not abundant (<5 percent), but occasionally ranged to 25 percent; one sample of coarse-grained sandstone consisted of over 50 percent lithic components. Most fragments were of sedimentary origin with secondary metamorphic types. Shale fragments (carbonaceous or bituminous) and disseminated and finely divided coal detritus were common. Other sedimentary components included chert and cherty sandstone, argillaceous sandstone, and argillite (sometimes silicified). Metamorphic fragments included quartzite, slate, chlorite, and muscovite.

Feldspar, predominantly plagioclase, typically constituted <3 percent; it occurred in twinned (albite and Carlsbad) and untwinned varieties. Microcline occurred in a few samples. Almost all feldspar grains were highly altered to sericite, chlorite, or other clays; some had limonite rims. Relatively fresh feldspar grains of pyroclastic origin(?) were not observed in the sandstone.

Biotite, the most abundant mica (≦7 percent), was usually deformed by compaction and often altered to kaolinite clay. Sericite mixed with chlorite, prochlorite, and clay typically constituted <2 percent, muscovite <1 percent.

Opaque and heavy minerals were estimated at <5 percent in modal analyses but occasionally ranged to 15 percent. The heavy minerals usually occurred as isolated grains but in some samples were concentrated in defined laminae; among those identified were tourmaline, apatite, rutile, zircon, garnet, epidote (the latter ≦1 percent), clinozoisite (≦5 percent), and hornblende. Typically, 10-50 percent of the heavy-mineral fraction was opaque.

Most sandstone examined had siliceous or argillaceous matrix. Often silica and clay were mixed. Cryptocrystalline silica was a common matrix material (including void-filling chalcedony) and was the cement in most samples; ferruginous and sometimes silty clays were also common cements. Illite and kaolinite were most abundant, usually stained by iron oxides and hydroxides and mixed with sericite, chlorite, and chlorophaeite. A small proportion of the clay minerals were authigenic. In finer grained sandstones, clay constituted 20-30 percent of the matrix.

Classification

Lithic or sublithic arenite and graywacke were the predominant sandstone types. Protoquartzites or orthoquartzites were not present in the Tyonek Formation samples analyzed.

Roundness, sorting, and textural maturity

Most quartz grains were subangular to subrounded. A few well-rounded grains were undoubtedly recycled and some showed abraded overgrowths. Some clay-coated grains also occurred, either recycled or with the coat formed authigenically by alteration. Chert clasts were typically more angular than quartz, especially in the coarser grained sandstone. Sorting was generally poor to moderate, and most sandstone was submature to immature.

Claystone

Claystone is common in the coal-bearing strata of the Tyonek Formation in the Susitna lowland. It may be silty or sandy locally and is often carbonaceous (with shreds of organic matter, coaly streaks, and carbonized plant fragments) or ferruginous (with iron oxide and hydroxide mottles, irregular patches, encrustations, rims, and fracture coats) and contains highly altered slate, quartzite, and graphitic or phyllitic schist fragments. It is cryptocrystalline, with included flakes typically oriented parallel to the bedding planes; it may have discontinuous, very fine laminae. Some samples were banded with light and dark lenses of finer and coarser grained material. The lighter lamellae were siltier and contained significantly more quartz than the darker lamellae of clay. Underclays commonly contained fossil roots, and sometimes regular black cryptogranular spheres that may be pollen grains. Claystone color ranged through shades of gray and brown, sometimes with tints of red, yellow, and green. Root casts were sometimes observed, and shrinkage cracks also occurred in some samples.

X-ray diffraction of claystone samples revealed that illite-kaolinite associations are most common, with secondary abundances of mixed-layer minerals such as chlorite and montmorillonite. Mixed-layer minerals and illite compete for the same sites, causing illite peaks to appear fairly broad and asymmetric on diffractograms. The illite may also be poorly ordered because of surficial weathering. Chlorite, clinochlore, and sericite occur as alteration products of hornblende or other ferromagnesian silicates and are intermixed with other clays. In the samples, kaolinite exhibited generally lower birefringence than did illite and sericite.

Cryptocrystalline quartz occurred in most thin sections of claystone as scattered minute fragments, small and irregular silicic veins and veinlets, and cavity fillings; chalcedony and opal were common. Quartz constituted <10 percent in most modal analyses but was usually the second main constituent.

Minor or accessory minerals and inclusions occurred in the claystone in numerous forms; carbonaceous (organic) matter was <7 percent on a modal basis. Opaque minerals were usually <5 percent. Biotite was the predominant mica (<5 percent) with minor muscovite (<1 percent), both highly altered; clinozoisite (often 2-7 percent) was more abundant than epidote (usually <1 percent).

Other occurrences included anatase, garnet, spinel, tourmaline, laumontite (zeolite in slate and schist fragments), and antigorite. Calcite, dolomite, siderite, and pyrite were extremely rare in these fine-textured sediments.

Carbonaceous shale

Carbonaceous shale is rare in coal-bearing strata of the Tyonek Formation in the Susitna lowland, typically occurring in very thin (<0.5 m) beds of reddish to dark brown or black undifferentiated clay and fine silt next to coal seams. Irregular, silicic veinlets and cavity fillings of cryptocrystalline quartz transected carbonaceous fragments. Minor accessory minerals included iron oxides and hydroxides, clinozoisite, epidote, sericite (minute shreds), muscovite, cryptogranular chlorite, feldspar (altering to clinozoisite), anatase, and tourmaline.

Carbonate content and concretions

The carbonate content of Tyonek Formation rocks studied was very low. Siderite concretions and differentially calcium-carbonate-cemented sandstone lenses occurred locally in coal-bearing sections. Microscopically, the rocks included a mixture of very fine-grained calcite and siderite with argillaceous matter and silt-sized to fine sand-sized quartz. The lenses and concretions occurred in sections near Capps, Wolverine, and Saturday Creeks. The differentially cemented lenses were most abundant in sandstone, whereas the siderite concretions occurred mainly in silty shale. Some concretions had weathering rinds of limonite or hematite.

Tonsteins

Several tonsteins have been identified as thin claystone partings in coal seams of the Tyonek Formation. Ovoids of relatively clear kaolinite are definitive of graupen tonsteins. The major-oxide geochemistry for two tonsteins (table 3) was generally consistent with an air-fall-tuff origin. X-ray diffraction of one tonstein (fig. 25) showed the chief constituent to be kaolinite; the samples contained little quartz. The high phosphate

Table 3. *Major-oxide geochemistry of two coal tonsteins from the Susitna Lowland.*

Oxide	Sample CnC7-12	Sample CG4-6
SiO_2	26.37	40.63
Al_2O_3	24.02	31.31
Fe_2O_3	1.22	0.42
MnO	0.00	0.01
MgO	0.15	0.09
CaO	3.28	0.62
Na_2O	0.00	0.13
K_2O	0.39	0.20
TiO_2	0.61	1.67
P_2O_5	8.64	0.13
LOI[a]	20.94	20.00
H_2O·	88.86	96.43

[a]Loss on ignition.

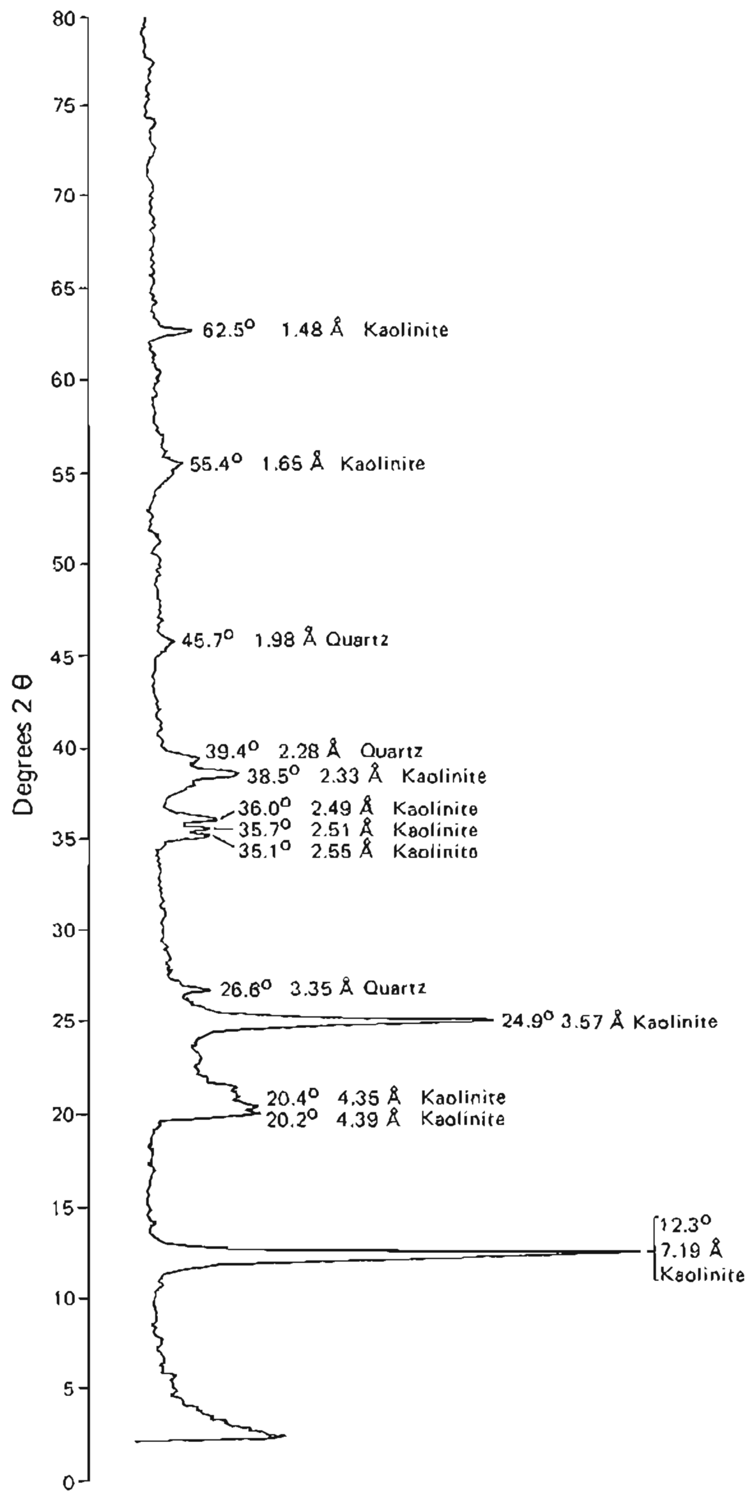


Figure 25. X-ray diffractogram of a coal tonstein (sample CC4-6) from the Capps bed. The chief constituent is kaolinite.

content in sample CnC7-12 was tentatively identified by X-ray diffraction as goyazite [$SrAl_3(PO_4)_2 \cdot (OH)_5 \cdot H_2O$] or gorceixite [$BaAl_5(PO_4)_2 \cdot (OH)_{11}$], members of an isostructural group of rhombohedral phosphates of the plumbogummite family (Price and Duff, 1969). A definitive identification of a specific hydrated aluminum phosphate was not made because other minerals of the series had similar 2 θ angles and peak intensities. Relatively high titanium (particularly noticeable in sample CG4-6) probably occurs as anatase, which was identified petrographically.

The tonstein samples CG4-6 and CnC7-12 exhibited the textures and general features of a palagonite tuff or recrystallized baked clay. Angular fragments (sometimes shards) of red and black devitrified (to various stages) volcanic glass were present. Kaolinite was often intermixed with iron oxides and hydroxides (goethite, limonite, and hematite) and showed parallel orientation with aggregate polarization. Chlorite and cryptogranular alteration products were concentrated along silicic (chalcedonic) veinlets; clinozoisite, epidote, and sericite also occurred as alterations.

Baked rocks

Several thermally altered rocks were also examined petrographically. The rocks were baked or burned by the natural combustion of adjacent coal beds or by an intruding dike or underlying sill. The degree of alteration is directly proportional to the rock's distance from the burning seam or igneous intrusion. A contact aureole caused by metamorphism is formed around the burned zone or intrusion. Ultimate products of the two processes (natural baking vs. contact metamorphism) are very similar and may be difficult to distinguish in a local area, particularly if a coal seam has burned underground.

A series of baked rocks (samples CnC3-1 through CnC3-5, table 4) was sampled at an upper Canyon Creek locality of the western Susitna lowland (fig. 26).

Table 4. *Major-oxide geochemistry of a gradational series of baked rocks from an upper Canyon Creek locality.*

Major oxide	CnC3-1[a]	CnC3-2[b]	Sample CnC3-3[c]	CnC3-4[d]	CnC3-5[e]
SiO_2	49.32	69.60	49.03	46.06	67.56
Al_2O_3	29.26	18.22	36.50	34.96	15.06
Fe_2O_3	1.93	1.02	2.17	4.36	4.20
MnO	0.01	0.01	0.02	0.15	0.07
MgO	0.21	0.04	0.25	0.56	0.20
CaO	0.70	0.55	1.00	2.34	0.47
Na_2O	0.22	0.24	0.26	0.66	4.71
K_2O	0.46	0.48	0.56	1.12	3.50
TiO_2	0.62	0.96	0.67	0.74	0.41
P_2O_5	0.18	0.17	0.27	0.44	0.14
LOI	9.97	3.88	2.91	2.65	1.07
H_2O	6.37	2.54	2.44	2.25	0.68
Total	96.25	97.71	96.08	96.29	97.97

[a] - Shale, carbonaceous, relatively unaltered
[b] - Light-gray baked claystone with abundant plant fossils
[c] - Beige baked claystone
[d] - Pink to light-red scoriaceous clinker, abundant hematite
[e] - Dark-red to maroon burn, high hematite.

Figure 26. Gradational zones of burn material in a coal-bearing section of the Tyonek Formation, upper Canyon Creek, southwest Yentna basin. Photograph by J.E. Sperber, 1981.

Although these rocks may have been altered by an underlying late Tertiary dike or sill, they were probably baked by the burning of an adjacent underground coal seam. Table 4 shows the geochemical changes that occur in baking: (1) a general increase in total iron as Fe_2O_3; (2) an increase in Na_2O and K_2O; and (3) an expected decrease in H_2O and LOI. No trends were noted in other major oxides.

The baked claystones had a very fine grained matrix that extinguished in two principal directions. Pores, voids, and veinlets were commonly filled with cryptocrystalline quartz. Identification of individual minerals became more difficult with increased alteration, because the minerals had recrystallized and showed indefinite boundaries, with flow banding and glass sometimes observable in thin section.

DEPOSITIONAL ENVIRONMENTS OF KENAI GROUP COALS

Source areas adjacent to basins of the Susitna lowland were rejuvenated during Late Cretaceous and early Tertiary time. Periodic or gradual uplift converted basinal flood plains into coal-forming environments by late Oligocene to middle Miocene time, when the Tyonek Formation was deposited. Vegetal and woody materials accumulated, and peat formed in these stagnant depositional areas. The ground-water table gradually rose, and the sediment supply was restricted, which also promoted peat formation.

Subsidence rates varied from area to area; gradual subsidence with periodic stillstands resulted in formation of coal swamps in paleotopographically low areas between flood events. At any one time, peat or coal would have been forming in relatively small areas of the region, as evidenced by the lack of extensive lateral continuity of the seams. Coal-seam partings also reveal nonuniform conditions over the Susitna lowland and indicate lateral shifting of swamps and other subenvironments.

Tertiary coal-bearing strata of the Kenai Group in the Susitna lowland have characteristics common to many continental fluvial models (see pl. 2). These predictive paleoenvironmental models are useful as exploration tools (for example, Horne and others, 1978) to indicate drill spacing during design of drilling programs. As channels and basin margins are approached, a closer spacing is required to delineate seam vagaries (Howell and Ferm, 1980). The thickest seams in a particular depositional basin usually occur next to depocenters and thin toward the periphery. Thicker coals within the continental fluvial system tend to parallel the depositional dip (Ryer, 1981). Paleoenvironmental models are useful as well in assessing coal quality and overburden characteristics during mine planning and in predicting geologic, geochemical (including hydrogeochemical), and environmental problems during mining and reclamation.

Fluvial depositional environments and subenvironments (natural levees, point bars, lakes, lacustrine deltas, abandoned-channel fills, crevasse splays and backswamps) influenced coal-seam and overburden characteristics of this regime (figs. 27 and 28; table 5). Backswamp deposits ideally consist of basal seatrock (often underclay), coal, and overlying carbonaceous shale. Discontinuities or splits in coal seams often represent ancient levee deposits of active channels, including crevasse splays, and local, pod-shaped coal bodies commonly represent accumulations of organic material next to meander channels of lushly vegetated ancient flood plains. Rapid sedimentation during floods buried this vegetation and frequently preserved upright stumps or kettles (Horne and others, 1978; fig. 29).

Dickinson and Campbell (1978) pointed to certain depositional environments for Tertiary Kenai Group sedimentary rocks in the Peters Hills and Fairview Mountain areas (most likely Tyonek Formation) of the Susitna lowland and concluded that some of these conglomerates and sandstones indicate near-source deposition in mudflows and proximal braided-stream systems on alluvial fans, whereas other conglomerates and sandstones of this region are characteristic of distal braided-channel and flood-plain deposits. They reported that these rocks are typically arkosic, oxidized at the surface, and composed mainly of

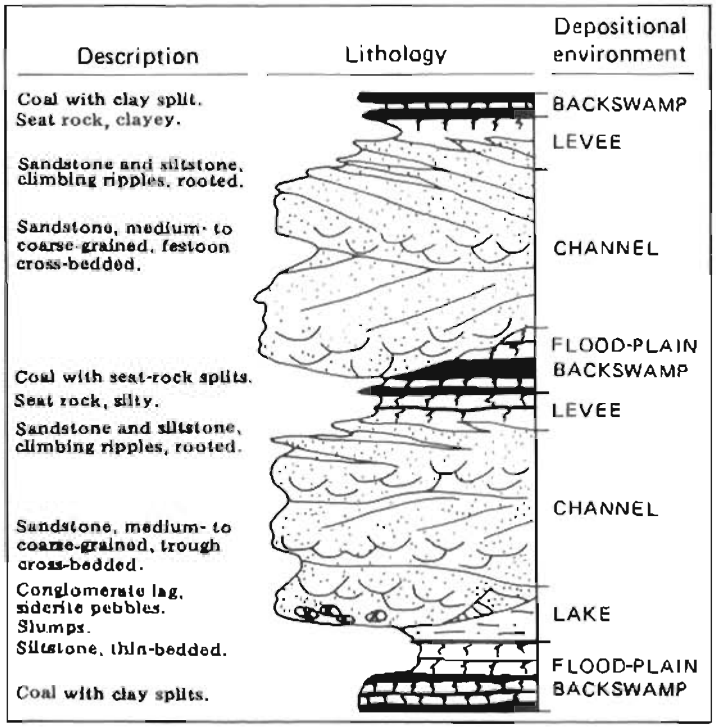


Figure 27. Generalized vertical sequence of continental fluvial deposits. Modified from Horne and others (1978).

quartz, plagioclase, and lesser orthoclase. Carbonaceous mudstone, claystone, and coal formed in interchannel lacustrine and paludal areas. The mudstone and claystone contain abundant illite and chlorite clay minerals, with minor siderite and calcium carbonate concretions.

A small synclinal basin east of Beluga Lake in the Susitna lowland contains a thick coal seam that may represent a lacustrine coal (fig. 30); it is similar to the basin-center coal and fringing marginal-shale-facies lacustrine model proposed by Hacquebard and Donaldson (1969) for basins in Nova Scotia.

Channels (represented now by channel-fill deposits) directly affect the minability of a particular coal seam (Horne and others, 1978); they are con-

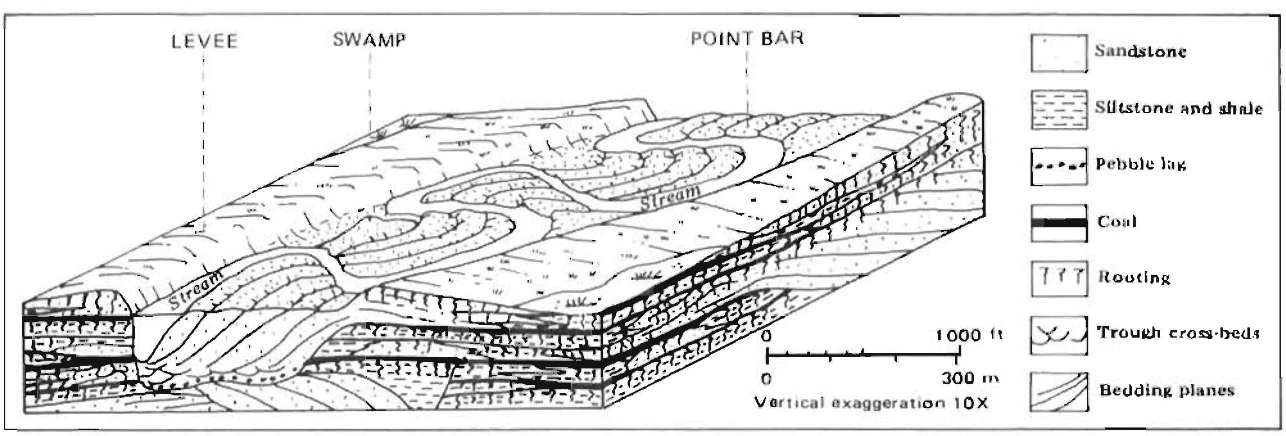


Figure 28. Block diagram of continental fluvial environments typical of the Susitna lowland. Modified from Horne and others (1978).

temporaneous with or postdate peat accumulation. A small paleochannel in a section of the Tyonek Formation near the western margin of the Susitna lowland has eroded much of a Saturday Creek coal seam.

Most stratigraphic sequences within the Tyonek Formation of the Kenai Group display a fining-upward character. Although at some locales the formation displays cyclic characteristics, these are not classic cyclothems. A typical full cyclic sequence includes (from bottom to top) conglomerate, often an immature petromictic conglomerate; pebbly, very coarse grained sandstone; medium- to coarse-grained sandstone; fine-grained sandstone; fine-grained sandstone interbedded with shale and siltstone; underclay, carbonaceous shale, or siltstone; and coal. A complete cycle is extremely rare because of erosion and truncation. Full sequences are predicted to occur nearer the depositing channel (Duff and others, 1967).

Table 5. *Criteria for recognition of fluvial depositional environments (from Horne and others, 1978).*

Characteristic	Frequency
Coarsening upward	
Shale and siltstone sequences	Common to rare
Greater than 50 ft	Not present
5 to 25 ft	Common to rare
Sandstone sequences	Rare to absent
Greater than 50 ft	Absent
5 to 25 ft	Rare
Channel deposits	
Fine-grained abandoned fill	Rare
Clay and silt	"
Organic debris	"
Active sandstone fill	Abundant
Fine grained	Common
Medium and coarse grained	Abundant
Pebble lags	"
Coal spar	"
Contacts	
Abrupt (scour)	"
Gradational	Common to rare
Cross-beds	Abundant
Ripples	Common
Ripple drift	Abundant to common
Herringbone festoon	Abundant
Graded beds	Rare
Point bar accretions	Abundant
Irregular bedding	"
Levee deposits	"
Mineralogy of sandstones	
Lithic graywacke	"
Orthoquartzites	Absent
Fossils	
Marine	"
Brackish	Rare
Fresh	Common to rare
Burrow structures	Rare

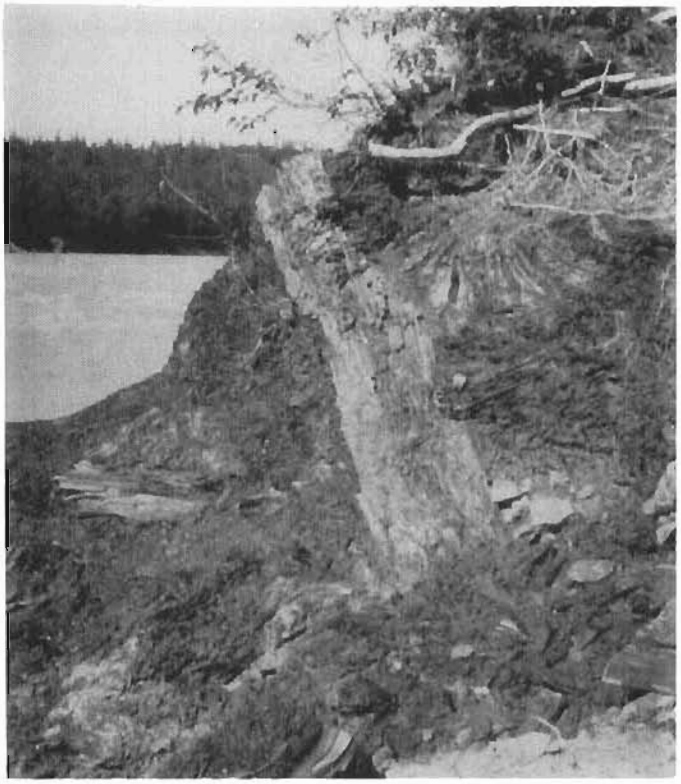


Figure 29. In-place, upright tree stump in woody coal (Beluga Formation) along the Beluga River, southern Susitna lowland. Photo by J.G. Clough, 1981.

These cycles result from shifts of channel and sediment deposition across an alluvial plain. The coarser basal units represent lateral-accretion deposits and are commonly crossbedded. The upper, finer grained, units represent overbank and lake or swamp deposits. As proposed, the flow-regime intensity progressively decreases upward in the section.

Cyclicity in the Susitna lowland was best preserved at Fairview Mountain (sheets 1 and 2; app. C). A statistical Markov-chain analysis was applied to the sequence based on the repetition of the five major rock types (conglomerate, sandstone, shale, claystone, and coal). The analysis followed the procedure outlined by Gingerich (1969) for Paleocene fluvial sedimentary rocks in the northern Bighorn basin of Wyoming. Calculations related to the analysis of the Fairview Mountain section are included as appendix D. With $\chi^2 = 35.9$ and 15 degrees of freedom, it is highly improbable that the Fairview Mountain sequence was deposited by an independent or non-Markovian mechanism; evidence indicates cyclic sedimentation in an alluvial environment (fig. 31).

These cycles indicate quiescent periods (tectonic lulls) during the Tertiary Period when large areas of basin flood plains became coal-forming swamps. These tectonic lulls were interrupted by periods of uplift and relatively rapid basin subsidence accompanied by the influx of clastic materials. In general, the Tertiary Period was a time of widespread but discontinuous coal formation in the Susitna lowland. Conditions conducive for coal formation were most favorable during late Oligocene to middle Miocene time, when the Tyonek Formation was deposited.

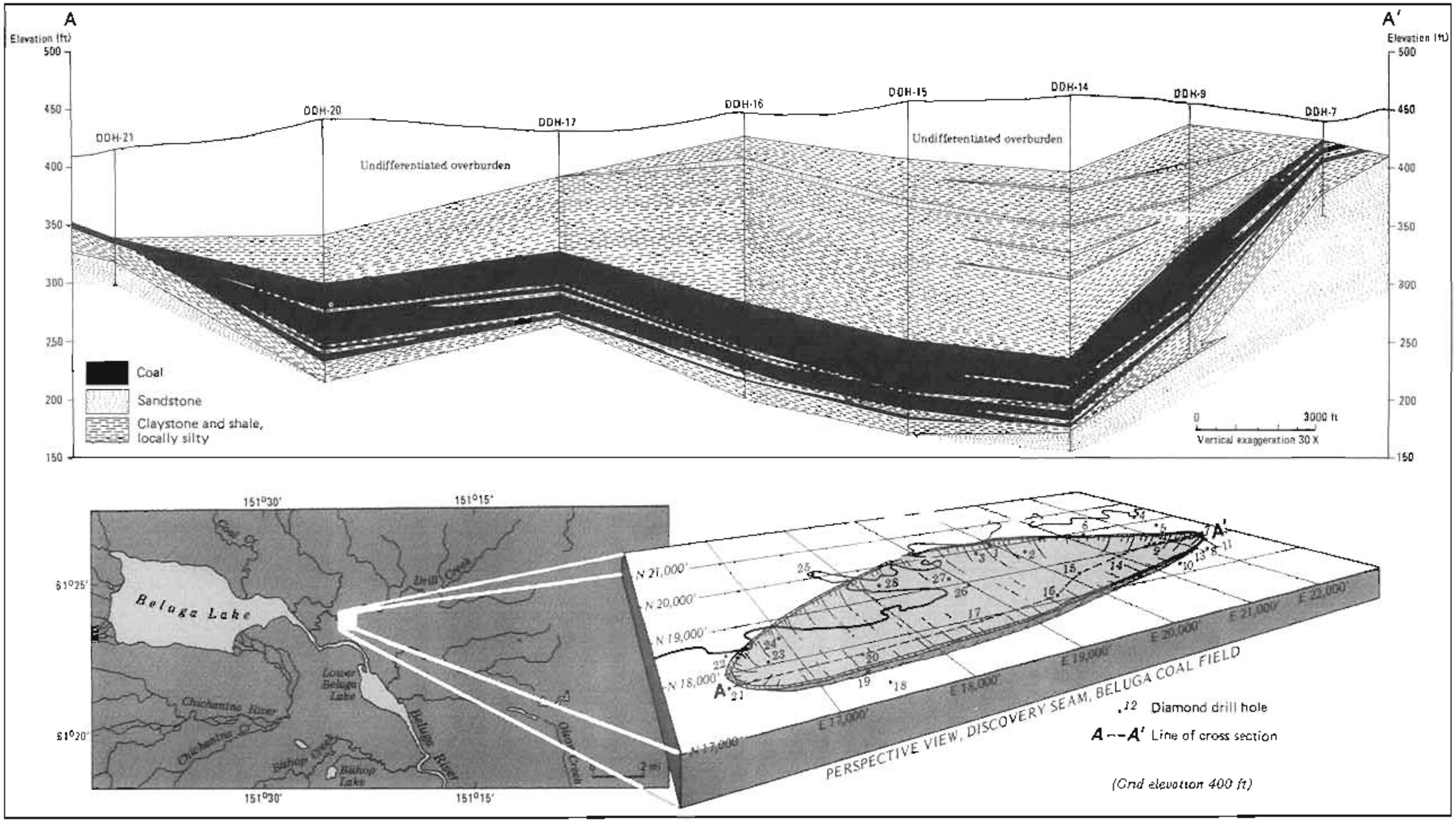


Figure 30. Geologic cross section of a lacustrine deposit in the Beluga coalfield. Lower insets (modified from Warfield, 1962) show the location of the deposit.

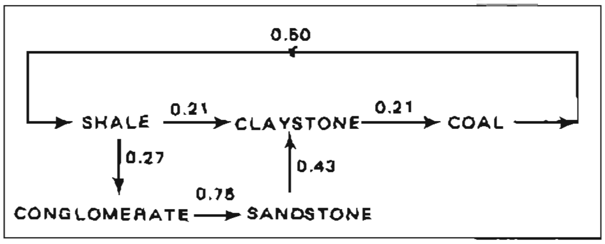


Figure 31. Probabilities of various transitions in lithology in a coal-bearing section of the Tyonek Formation, Fairview Mountain.

Various workers have related the paleosalinity of strata to paleoenvironmental interpretation; for example, to decipher marine transgressions and regressions. Couch (1971) calculated paleosalinities from boron and clay-mineral data. Bohor and Gluskoter (1973) used boron in illite as an indicator of paleosalinity in Illinois coals; Berner and others (1979) used authigenic iron sulfides.

Using exchangeable cations and water-soluble cations as paleosalinity indicators, Spears (1973; 1974) found that the concentration of exchangeable magnesium is higher in marine shales, and the concentrations of exchangeable calcium, sodium, and potassium lower, than in nonmarine and brackish shales; he correlated the changes in exchangeable cations to paleosalinity throughout the sequence and postulated that these changes more likely occurred during halmyrolysis (submarine weathering) than during diagenesis (1973, p. 79, 81). He proposed (1974) that high concentrations of water-soluble calcium and magnesium cations reflect marine-influenced environments, whereas low concentrations are diagnostic of freshwater and brackish-water paleoenvironments; sodium and potassium have reverse trends.

Figure 32 shows considerable variation in the ammonium acetate extractable cations and total cation-exchange capacity (CEC) for a coal-bearing section in the Tyonek Formation near Peters Hills. Increases in extractable Mg^{++}, Ca^{++}, and K^{+} are mirrored by an increase in total CEC. Spears (1973) found a corresponding decrease in total CEC with increasing exchangeable magnesium. Changes in CEC are also directly related to changes in mineralogy; in this example, a reduction in CEC simply reflects a decrease in the amount of clay and is probably related to provenance. The Peters Hills section was probably deposited in continental fluvial environments, and the variations are therefore not related to transitions with marine environments.

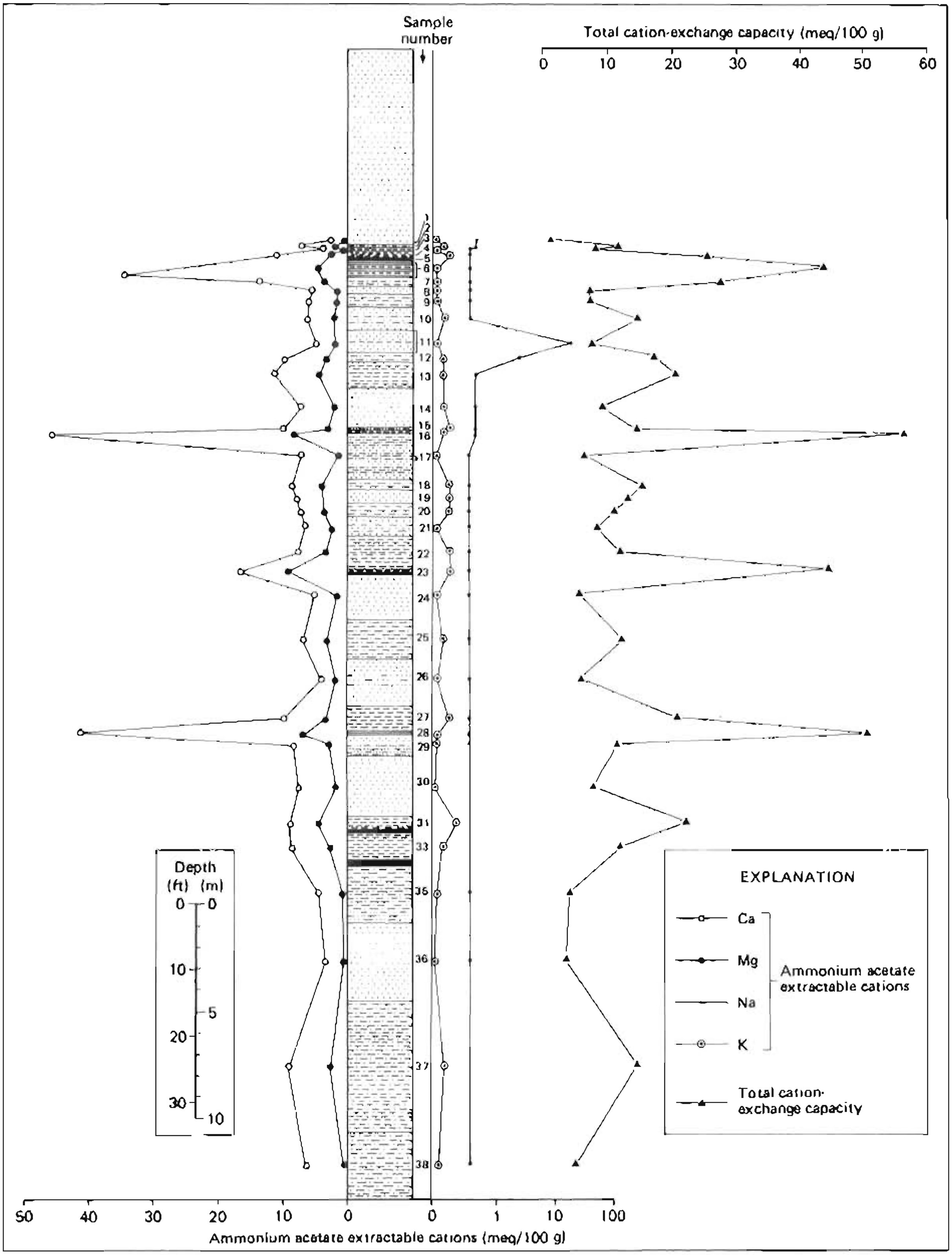


Figure 32. Variation in ammonium acetate extractable cations and total cation-exchange capacity (CEC) for a coal-bearing section in the Peters Hills area (east Yentna field, Tyonek Formation).

Table 6. *Nomenclature and characteristics for major brown coal - lignite macerals (from Crelling and Dutcher, 1980; Stach and others, 1975).*

Maceral group	Origin	Abundance	Characteristics Chemistry	Reflectance	Fluorescence	Maceral subgroup	Maceral	Maceral type	Comments
Huminite	Derived from woody or vascular tissues of plants—cell-wall material, stems, roots, or bark	Generally makes up 50-90% of most coals	Carbon and hydrogen contents are intermediate between liptinites and inertinites	Intermediate between liptinites and inertinites	Some macerals exhibit a weak brownish fluorescence when excited by ultraviolet light	Humotelinite	Ulminite	Texto-ulminite	Alteration product from textinite, partially gelified
								Eu-ulminite	Alteration product from textinite, completely gelified
							Textinite	--	Humified tissues which are ungelified and still resemble the original cell walls, characterized by open cell lumens
						Humo-detrinite	Attrinite	--	Humic detrital particles and finely divided and mainly porous gel which are loosely packed and well differentiated from one another
							Densinite	--	Individual humic detrital particles and finely divided humic gel, cemented tightly together
						Humo-collinite	Gelinite	Porigelinite	Finely porous to granular gels originating from colloidal humic solutions
								Levigelinite	Three forms—eugelinite (dense and massive), telogelinite (completely gelified tissues), and detrogelinite (humic detritus occurring as cavity fillings—shrinkage cracks, cleats, root ducts).
							Corpohuminite	Phlobaphinite	Primary cell infillings liberated as exretions from living plant cell walls.
								Pseudo-phlobaphinite	Produced as secondary cell infillings from humic gels.
Liptinite (exinite)	Derived from the waxy and resinous parts of plants such as spores, cuticles, and wound resins	Usually makes up 5-15% of most coals	Lowest carbon and highest hydrogen contents of all macerals	Lowest reflectances of all macerals	All fluoresce when excited by ultraviolet light		Sporinite	--	Spore and pollen perines and exines; takes the form of a flattened spheroid, upper and lower hemispheres compressed until they come together.
							Alginite	--	Algal remains, rare; fluoresces brilliant yellow under light
							Cutinite	--	Cuticles of leaves and stems; occurs as long stringers with one surface fairly flat and the other crenulated
							Resinite	--	Resins, plant secretions, and exudates; occurs as ovoid bodies or fissure-filling material
							Suberinite	--	Cork cell walls which occur mainly in barks
Inertinite	Derived from plant material that has been strongly altered and degraded in the peat stage of coal formation; e.g., fossil charcoal	Composes from less than 5% up to 40% of most coals	Highest carbon and lowest hydrogen contents of all macerals	Highest reflectances of all macerals	Does not fluoresce		Macrinite	--	Minor component; occurs as structureless ovoid bodies with the same reflectance as fusinite; may have globular appearance.
							Fusinite	--	Charcoallike structure with a cell texture; commonly broken in small shards and fragments (bogen).
							Semifusinite	-	Same cell texture as fusinite but of lower reflectance.
							Sclerotinite		Formed from hard fungal remains; occurs as ovoid bodies with cell structure.
							Inertodetrinite	--	Clastic form of inertinite; fragments of different inertinite macerals occurring as dispersed particles.

COAL PETROLOGY

Coal-pellet preparation and petrologic analysis

The procedures of the International Committee on Coal Petrology (1963) and the terminology for brown coal from Stach and others (1975) were adopted for this petrologic analysis of Susitna lowland coals (table 6). A 50-g sample of each coal (-20 mesh) was kneaded with epoxy resin as a binder and briquetted in 3.2-cm-diam molds with a hydraulic press at 4,000-5,000 psi. The pellets were consecutively ground using a Buehler automet, a 120-μ diamond lap, and a 30-μ metal-bonded diamond lap, and then polished in 1- and 0.05-μ aluminum oxide suspensions (2 min each stage).

A Swift point counter was used to quantitatively determine macerals. On each pellet, 1,000 counts were made along a grid traverse. The maceral content was recorded on a volume-percent and mineral-matter-free basis. No separate count was made for liptinite macerals and fluorescent huminites under fluorescent incident-light excitation; however, liptinites were studied under blue ultraviolet light, and representative photomicrographs of the different types were taken. The fluorescence system consisted of a Leitz SmLux microscope with a Ploempak fluorescence incident-light illuminator and 100-W mercury lamp fitted with an I2 cube (Rao and Wolff, 1981).

Reflectance measurements were made on a Leitz Ortholux triocular-body microscope equipped with an MPV-3 system with a motorized drive stage. A square-leaf diaphragm with a 5-μ^2 measuring area on the specimen was used. In addition, an interference filter was fitted to give a peak transmittance at 546-nm wavelength. Bausch and Lomb optical glasses were used as reflectance standards. The mean maximum reflectance of ulminite particles was measured in oil along equally spaced traverses; 100 measurements were made on each sample. Before reflectance measurements were taken, polished pellets were dried in a desiccator (Rao and Wolff, 1981).

Maceral composition

Macerals, the organic constituents of coal--analogous to minerals in rocks--are identified by their diagnostic morphology and reflectance; however, the respective maceral composition of a coal gives only part of an overall picture, because of complex chemical composition and mineral-matter content. Structurally intact cell walls and relatively unstructured fine, granular materials (for example, mineral matter, fragmented charcoal, and fungal remains) sometimes occur. Although the maceral compositions usually reflect changes in the primary vegetation cover, thermal effects may remove less resistant macerals such as exinoids from the assemblage. The materials forming peats are subjected to different conditions before burial beneath a sediment cover. The changes that occur in the eventual maceral compositions ultimately determine the coal's quality and heating value.

Maceral compositions for Susitna lowland coal samples analyzed in this study are summarized in table 7 and on figure 33. Raw coals from different areas within the Susitna lowland have similar maceral-group proportions. However, the relative contents of individual macerals and maceral types may vary considerably within a seam and among different seams, as shown in photomicrographs of coals from the region (figs. 34 and 35).

Table 7. *Summary of maceral composition of 180 coal samples from the Susitna Lowland. (Reported on a volume-percent, moisture- and ash-free basis.)*

	Range (%)	Mean (%)
Ulminite	15.8- 99.0	65.0
Porigelinite	0.0- 35.4	9.0
Phlobaphinite	0.0- 18.2	2.7
Pseudophlobaphinite	0.0- 21.6	3.9
Humodetrinite	0.2- 63.2	15.7
Total huminite	76.6-100.0	
Fusinite	0.0- 9.6	0.6
Semifusinite	0.0- 5.2	0.3
Sclerotinite	0.0- 1.4	0.1
Macrinite	0.0- 2.0	0.9
Inertodetrinite	0.0- 5.2	0.2
Total inertinite	0.0- 18.6	
Cutinite	0.0- 3.4	0.4
Sporinite	0.0- 5.6	0.4
Resinite	0.0- 9.2	1.0
Suberinite	0.0- 3.8	0.5
Alginite	0.0- 2.0	0.05
Total liptinite	0.0- 11.8	

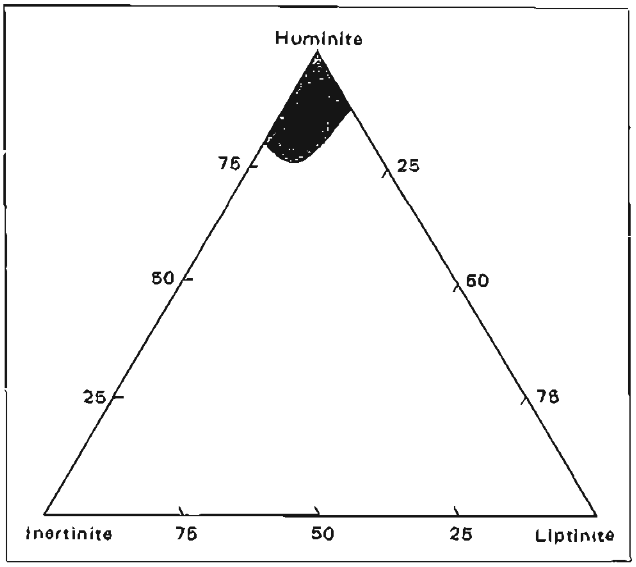


Figure 33. Ternary diagram for maceral-group compositions of Susitna lowland coal samples.

Huminite macerals were by far the most abundant in coals of the Susitna lowland; the huminite group typically accounted for 90 percent, and never <75 percent, of all macerals (see table 7). Ulminite, the main huminite to occur, was medium to light gray, generally uniform in structure and reflectance, and sometimes displayed desiccation cracks or microfractures. Texto-ulminite was partially gelified, and eu-ulminite was completely gelified. Corpohuminites occurred as phlobaphinite (primary cell infillings) and pseudophlobaphinite (secondary cell infillings). Pseudovitrinite was extremely rare and was not identified. According to Rao and Wolff (1981), humodetrinite content (finely dispersed humic debris) is most abundant in the top seam of a coal-bearing sequence. They postulated that the changing paleoenvironmental regime caused physical degradation of humic matter and ended conditions conducive to coal formation. This trend was not well established in most Susitna lowland coal-bearing sequences but was observed in some coal-bearing sections.

Mean-maximum-reflectance values for all coals as measured from ulminite macerals are listed in appendix B, table B-3, compared by respective ASTM (American Society of Testing and Materials) rank in table B-4, and summarized in figure 36. Reflectance values ranged from 0.23 to 0.45 percent, which confirms that most coals are subbituminous to lignitic. Little variation occurred in the reflectance values within a seam or among seams.

Inertinites commonly occurred as minor constituents in Susitna lowland coals. However, several seams, particularly those in the northern Yentna coalfield at Fairview Mountain and in the Peters Hills area, yielded samples with inertinitic contents of more than 18 percent by volume on a mineral-matter-free basis (see table 7). These inertinites were typically white or very light gray and bright in normal incident light and exhibited the highest reflectance of all the macerals. Macrinite, fusinite, and semifusinite predominated, but inertodetrinite (dispersed clastic fragments of inertinite) and sclerotinite (hard fungal remains usually in young coals, as those of the Tertiary Period) were also observed. Sclerotia were rounded or elliptical, with lumens or cavities occasionally containing resinite, pyrite, or other mineral matter. Micrinite was not identified in coals of this region.

The inertinites were affected by more intense physical and chemical alteration than were the huminites, but both are chiefly derived from wood and bark. The inertinites may have been attacked by bacteria before burial. Fusinitic and semifusinitic components consisted of charcoal and other partially burned materials. These macerals are thermally resistant and inert; hence, they are not easily oxidized or hydrogenated. Rao and Wolff (1981) found that the concentration of inert macerals increased from the base to the top of a given seam, and they believed this trend to reflect a gradual change to a drier paleoenvironment during coal formation.

Liptinites (exinites) in Susitna lowland coal samples ranged to about 12 percent by volume on a mineral-matter-free basis (table 7). Resinite and suberinite were the most abundant. Liptinites have the lowest reflectances of all macerals. They are black to dark gray in normal incident light, but fluoresce under blue-light irradiation. Liptinites share broad chemical affinities, such as relatively high hydrogen and volatile contents; compared with other maceral groups, they have a higher concentration of aliphatic substances such as tar. Liptinites can represent diverse coal components that range from spore and pollen exines and perines to cuticles, algae, and other resinous substances, and tannin derivatives (Spackman and others, 1976).

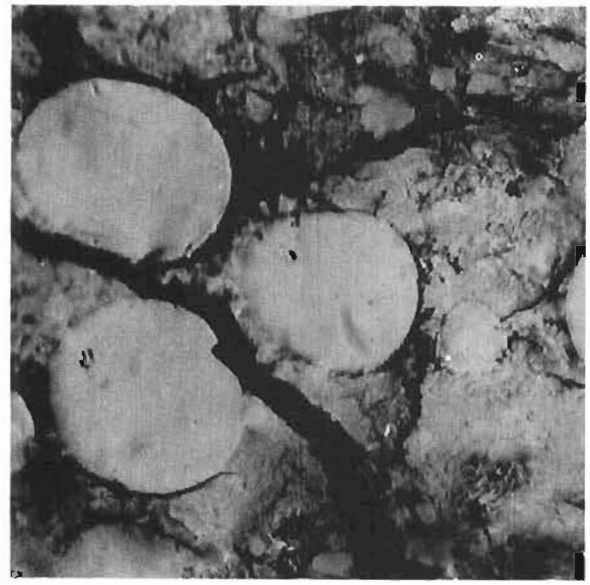
Resinite occurred as cell fillings of lumens, or as secretions, and sometimes as isolated, elongate, or spherical bodies; resinite typically displays an orange fluorescence. Exsudatinite, included with resinite, commonly fills cracks in vitrinite (ulminite), cell lumina of fusinite, or chambers of sclerotinite (Spackman and others, 1976). Suberinite is common in Tertiary coals and originates from cork cell walls, mainly in bark and root tissue. Yellow stringers (in fluorescent light) of cutinite were typically crenulated or serrated on one side, thin walled (tenuicutinite) or thick walled (crassicutinite), and sometimes folded. Sporinite occurred as flattened elongate bodies with slitted centers. Alginites (preserved algal remains) were rare in the Susitna lowland coal samples; alginites fluoresce yellow under blue-light irradiation.

Hydrogenation (increasing the hydrogen content of a coal) is vital to the liquefaction and gasification processes. Generally, the vitrinite and exinite components of a coal can be hydrogenated but inertinites cannot; further petrologic and characterization research will help determine potential alternative uses and beneficiation processes that can be applied to Susitna lowland coals.

Paleoenvironmental interpretation for maceral compositions and associations

Paleoenvironmental interpretation from coal petrology begins with an understanding of the concept of microlithotypes--associations of macerals of the same group or associations with those from other maceral groups. They can

a. Phlobaphinite and porigelinite (PA3-1p; mag. 400X).

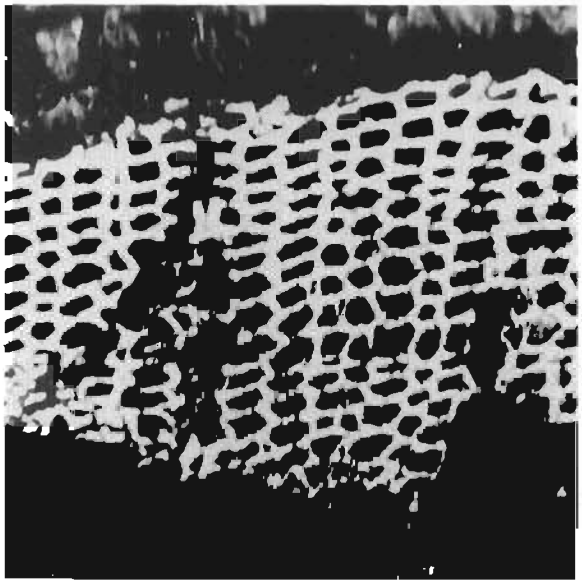


b. Pseudophlobaphinites (CC3-3p; mag. 250X).

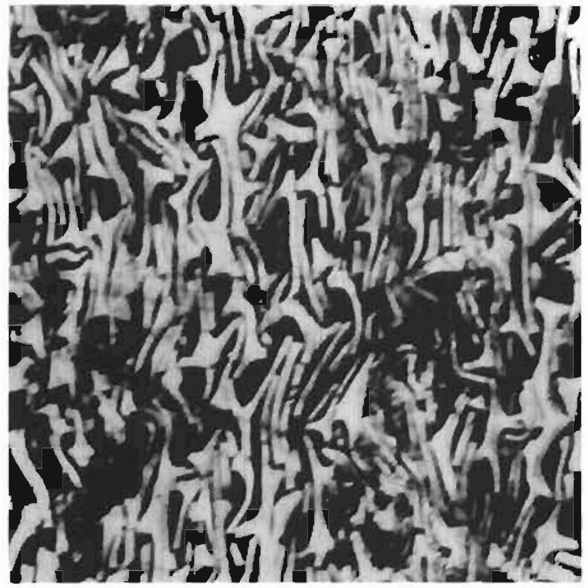
c. Phlobaphinite cell fillings and thick suberinite cell walls (PA3-1p; mag. 400X).

d. Sporinites in ulminite (JC3-5; mag. 625X).

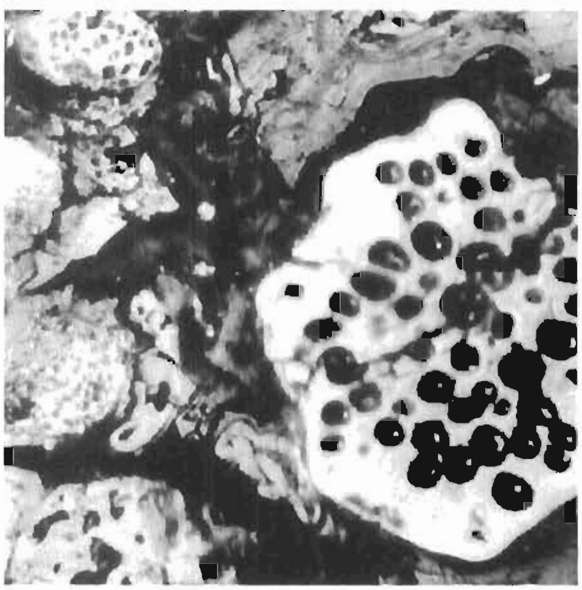
Figure 34. Photomicrographs of Tertiary (Tyonek Formation) coals from Coal Creek (Beluga field), Johnson Creek, and Peters Hills area (Yentna field) showing huminite and liptinite macerals (oil immersion). Photographs by R.D. Merritt, 1982.



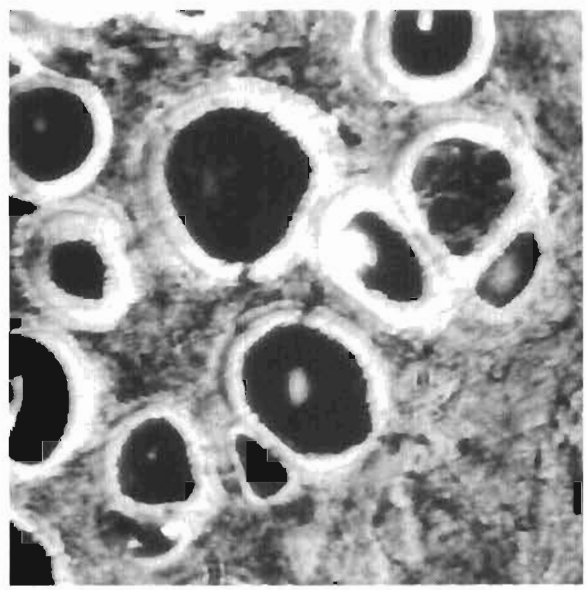
a. Fusinite (CC3-4; mag. 315X).



b. Fusinite with bogen structure (FM2-1; mag. 400X).



c. Sclerotinite, ulminite and porigelinite (BB1-1p; mag. 315X).



d. Fungal spores with mineral matter and humic material (CC3-4p; mag. 625X).

Figure 35. Photomicrographs of Tertiary coals from Beshta Bay (Beluga Formation, Beluga field), Coal Creek (Tyonek Formation, Beluga field), and Fairview Mountain (Tyonek Formation, Yentna field) showing predominant inertinite macerals (oil immersion). Photographs by R.D. Merritt, 1982.

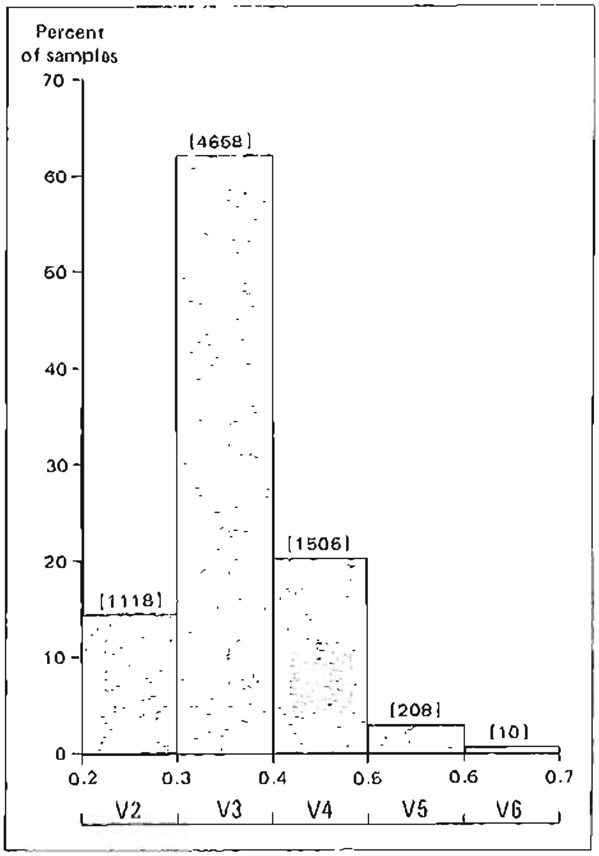


Figure 36. Histogram of vitrinite reflectance frequency (%) as measured from ulminite macerals in coal samples from the Susitna lowland. Numbers in brackets indicate total number of grains measured at a given reflectance interval; V = reflectance class.

be monomaceralic (microlithotypes that contain macerals of only one group), bimaceralic (with macerals of two groups), or trimaceralic (macerals of three groups). Table 8 summarizes the microlithotypes (Stach and others, 1975) that compose the macroscopic lithotypes: vitrain, clarain, durain, and fusain.

Coal samples from the Susitna lowland were not collected at vertical or lateral intervals close enough to permit detailed interpretation of facies changes within the coal seams; therefore, the main microlithotypes were very generally determined by selectively counting the maceral associations on the polished pellets and by interpreting the extensive maceral-composition data collected. Different groups of microlithotypes were subdivided into individual microlithotypes based on these maceral associations (Stach and others, 1975). Vitrite was the dominant microlithotype, with clarite that contains minor interbands of vitrinertite and trimacerite (duroclarite). Williams and Ross (1979) found similar maceral compositions and microlithotypes in Eocene bituminous coals from the Tulameen coalfield of British Columbia. They also found that vitrite was the dominant microlithotype, with clarite that contained minor interbands of trimacerite (clarodurite) and durite. From their maceral determinations, they proposed that the coal-forming peats developed in a forest-moor environment in a poorly drained, low-lying basin next to an eroding upland in a warm, moist climate.

When Cohen (1973) related precursor peat types to eventual coal composition, he differentiated two major peat groups: (1) herbaceous peats, which produce massive, unlaminated, dull coal; and (2) tree-vegetation peats, which result in brighter, laminated coal. He found that herbaceous peats are lower

Table 8. *Summary of microlithotypes (from Stach and others, 1975, p. 110).*[a]

Maceral composition (mineral-free)		Microlithotype	Maceral-group composition (mineral-free)	Microlithotype group
		Monomaceral		
Co[b]	>95%	(Collite)[a]	V >95%	Vitrite
T	>95%	(Telite)[a]		
VD	>95%			
S	>95%	Sporite		
Cu	>95%	(Cutite)[a]		
R	>95%	(Resite)[a]	E (L) >95%	Liptite
A	>95%	Algite		
LD	>95%			
Sf	>95%	Semifusite		
F	>95%	Fusite	I >95%	Inertite
Sc	>95%	(Sclerotite)[a]		
ID	>95%	Inertodetrite		
M	>95%	(Macroite)[a]		
		Bimaceral		
V + S	>95%	Sporoclarite		
V + Cu	>95%	Cuticoclarite	V + E (L) >95%	Clarite
V + R	>95%	(Resinoclarite)[a]		V, E(L)
V + LD	>95%			
V + M	>95%			
V + Sf	>95%			
V + F	>95%		V + I >95%	Vitrinertite
V + Sc	>95%			V, I
V + ID	>95%			
I + S	>95%	Sporodurite		
I + Cu	>95%	(Cutricodurite)[a]		
I + R	>95%	(Resinodurite)[a]	I + E (L) >95%	Durite
I + LD	>95%			I, E(L)
		Trimaceral		
V, I, E	> 5%	Duroclarite	V > I, E (L)	Trimacerite
		Vitrinertoliptite	E > I, V	V, I, E(L)
		Clarodurite	I > V, E (L)	

[a]Terms in parentheses not now in use.
[b]Co - Collinite; T - Telinite; VD - Vitrodetrinite; S - Sporinite; Cu - Cutinite; R - Resinite; A - Alginite; LD - Liptodetrinite; M - Macrinite; Sf - Semifusinite; F - Fusinite; Sc - Sclerotinite; ID - Inertodetrinite; V - Vitrinite; F - Fusinite; L - Liptinite; I - Inertinite; E - Exinite.

in preresinites (cell fillings and secretions), fusinite (charcoal), and pre-sclerotinites (fungal remains) but are higher in premicrinites (fine granular debris). Tree-vegetation peats, however, have a higher percentage of preresinites, presclerotinites, and fusinite but a lower percentage of premicrinitic materials. On the basis of this subdivision, most Susitna lowland coals probably formed from tree-vegetation peats.

The determination of the paleoenvironment in which a coal-forming peat developed extends back to a classic paper by Hacquebard and Donaldson (1969), who described how flood-plain and limnic environments in Nova Scotia were related to coal deposition during Carboniferous time (table 9). Hacquebard and Donaldson noted that coal-forming materials can accumulate in place, to form autochthonous coals, or can be transported to another region and accumulate to

Table 9. *Chief characteristics of autochthonous and allochthonous coals (modified from Hacquebard and Donaldson, 1969).*

Autochthonous coals	Allochthonous coals
a. Seams typically rest on underclays	a. Common absence of underclays
b. Occurrence of upright and rooted fossil trees	b. Absence of upright trees
c. Minor fluctuations in ash content both within and between seams	c. Relatively high percentages of ash
d. Wide distribution of seams and relatively uniform thickness of individual benches over large areas	d. Pronounced variability in quality and thickness of coals, which grade both laterally and vertically into dark-gray or black shales
e. Excellent preservation of delicate plant organs (such as leaves) in roof shales	e. Scarcity of plant remains in roofs of coal seams and in intervening shales
f. Presence of vitrain, clarain, durain, and fusain, and excellent preservation of macerals.	f. Consist predominantly of more resistant macerals as corpocollinites and certain liptinites and of inertinites with abundant mineral matter.

form allochthonous coals. Hypautochthonous coals originate mainly from plant debris transported within the general area of its growth, whereas allochthonous coal seams form from peats deposited as drifted vegetation--specifically, plant accumulations that drifted or were rafted into regions other than those in which they originally grew.

Evidence indicates that most Susitna lowland coals formed in place, but some coals exhibit characteristics of each group. Upright and rooted fossil trees occur locally; most leaf impressions are completely intact and indicate no transport. Some Susitna lowland coals have a classic underclay.

Hacquebard and Donaldson (1969) concluded that the most favorable locations for deposition of normal-banded autochthonous coals in a flood-plain environment are interdistributary troughs and levee-flank depressions along river channels or areas associated with lacustrine sedimentation. Coal seams as thick as 13.5 m are characteristic of the latter; compaction results in subsided, poorly drained areas favorable for formation of thick peat deposits (Hacquebard and Donaldson, 1969, p. 151). According to their model, distribution and accumulation of clastic sediments in a flood-plain environment are controlled by the river's course and transporting power. Coarser sediments are deposited in or next to the channel, particularly as natural levees; finer grained sediments are carried into interdistributary areas by overbank floodwater. Interaction between fluvial sedimentation and peat deposition results in splits or digitations in seams and their eventual 'pinch-out'. Changes in flood-plain environments are accompanied by changes in vegetation and in the corresponding types and abundances of macerals preserved. Rapid subsidence and early burial of peat beds result in excellent preservation of macerals.

At each sample location, Hacquebard and Donaldson (1969) subdivided the seam profile into petrographic intervals representing time-rock units. Each interval was bounded by clastic partings or by distinctive dull layers with a relatively widespread continuity and a characteristic microscopic composition. They expressed the aggregate thickness of individual microlithotypes as a percentage of an interval's total thickness and plotted those percentages on a four-component 'facies' diagram (fig. 37). The vertices of the triangles represent those microlithotypes (or combinations thereof) characteristic to specific environments in the peat bog.

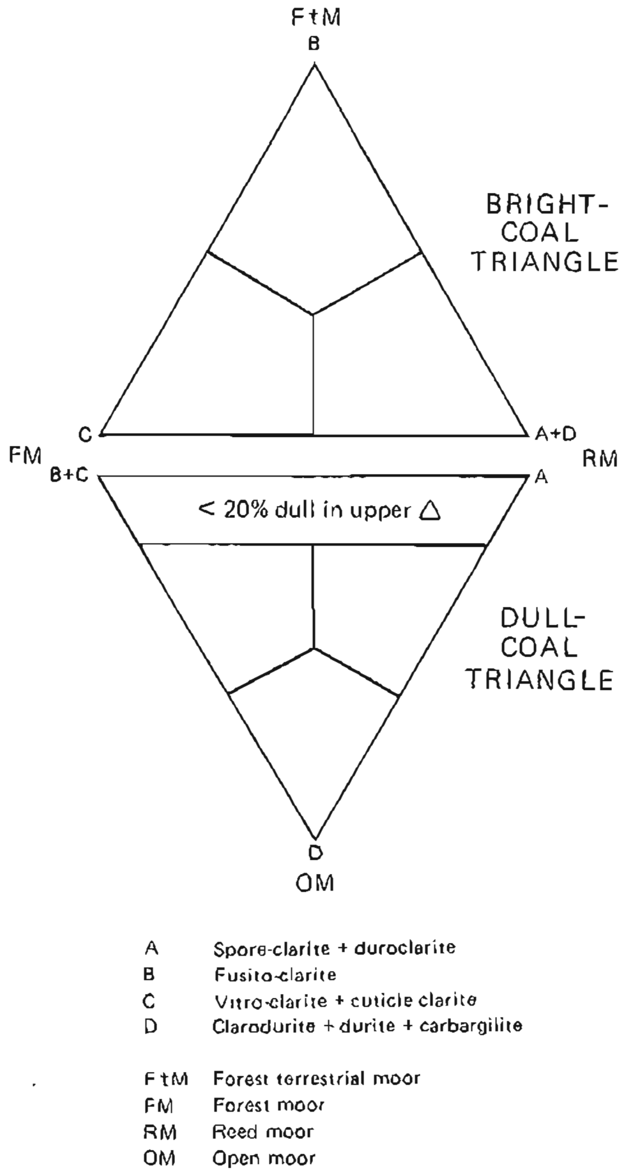


Figure 37. Four-component 'facies' diagram of individual microlithotypes in different petrographic intervals. FtM = relatively dry conditions, an environment for the formation of fusito-clarite; FM = an environment for deposition of vitrite and vitro-clarite; RM = an environment occupying transitional areas of reed growth, deposition of spore-rich clarite; OM = an environment for deposition of mainly subaquatic coals such as cannel and boghead and certain spore-rich clarite. Modified from Hacquebard and Donaldson (1969).

They then assigned four diagnostic vegetation zones (following the procedure of Karmasin, 1952) to the corresponding vertices of the combined triangles, to illustrate the paleoenvironmental origins of the microlithotypes. Forest-moor and reed-moor facies of the bright coal triangle formed in the telmatic zone between high and low water levels (Osvald, 1937). Subaquatic (open moor) deposits of the lowest sector of the dull-coal triangle formed in the limnic zone, and the two remaining sectors represent limno-telmatic deposits.

The microlithotypes most closely related to the Susitna lowland coals are those in the lower left sector of the upper bright-coal triangle (see fig. 37); these contain vitrinite (or huminite) and little sporinite. The forest-moor environment, where vitrite and vitro-clarite are the predominant deposits, is the typical depositional environment of most Susitna lowland coals (especially Tyonek Formation coals) and of Tulameen field (British Columbia) coals. The vegetation types and the conditions under which these plant materials were preserved indicate that most Susitna lowland coals formed in a telmatic zone.

Framboidal pyrite

Four major morphologic species of sedimentary pyrite or marcasite occur in coals and their associated sediments: (1) framboidal pyrite, (2) euhedral grains, (3) coarse-grained masses (>25-μ diam), which replace original plant material, and (4) coarse-grained platy masses or cleats that occupy joints. Disseminated euhedral grains (usually 1- to 10-μ diam) and framboids (>25-μ diam) are primary-pyrite varieties; coarse-grained, massive, and replacement forms are secondary. Framboidal pyrite is a microsopic aggregate of pyrite grains in unique 'raspberrylike' spheroidal clusters. The diameter of each microsphere varies from 0.25 to 1 μ, and these microspheres compose spherules up to 250 μ diam. Groups of framboidal spheres have been termed polyframboids (Caruccio and others, 1977). Pyrite or marcasite also occurs as microcrystalline rosettes (for example, as minute octahedrons).

Framboidal pyrite occurs in continental-fluvial, low-sulfur coals of the Kenai Group (for example, Capps Glacier area, Fairview Mountain, Peters Hills area, and Wolverine Creek sites). Until recently, the origin of framboidal pyrite seemed to involve sulfur-reducing marine or brackish-water microbial organisms, particularly bacteria. However, fine-grained pyrites were recently identified in till (Stene, 1979), unconsolidated mud and ancient shale (Czurda and others, 1973), and freshwater sediments (Dell, 1975). Organic matter and a reducing environment are prerequisites for framboidal pyrite formation, but, contrary to previous theory, sulfur-reducing bacteria such as Desulfovibrio desulfuricans (Berner, 1969; Sweeney and Kaplan, 1973), which are restricted to marine and brackish waters, are probably not required. Williams and Keith (1963) found that roof rock of marine or brackish-water origin contains more sulfur than roof rock of freshwater origin, and, indeed, pyrite morphology and grain size are partly controlled by the geochemical regime in ancient peat-swamp environments. However, because of the recent discovery of framboidal pyrite in a variety of sediments, paleoenvironmental interpretations cannot be based solely on their presence.

Most Susitna lowland coals contain <0.4 percent sulfur (table 10); thus, cleaning coal for sulfur would not generally be required. Coarse-grained, massive pyrite can be removed from coal by using the standard specific-gravity (sink-float) technique; organically combined pyrite, the most abundant type in Alaska coals, is difficult to remove. High sulfate-sulfur content in a coal commonly indicates a weathered sample (for example, WC1-3 of table 10).

Framboidal pyrite has been identified petrographically in certain Susitna lowland coals. Primary sedimentary sulfides rapidly oxidize to iron oxides and ferrous and ferric sulfates when exposed to air, but secondary pyrite is stable and is leached very slowly (Caruccio and others, 1977). Although framboidal pyrite is a major contributor to most acid-mine-drainage problems in coal-mining regions (Caruccio, 1970), these conditions are not expected in the Susitna lowland because of the minor amount of pyritic sulfur and disseminated reactive framboidal pyrite. In addition, contamination of surface and ground water by the solution and release of chemically bound trace elements in the primary sulfide fraction should not occur, because the quantity of disseminated pyrite in coals of southcentral Alaska is minor.

COAL QUALITY

Coals of the Beluga and west Yentna fields in Cook Inlet-Susitna lowland offer the greatest potential for near-term development. A revitalized coal-mining industry could also develop in the Matanuska Valley. Locally, coals of the Matanuska field have been upgraded to anthracite by complex folding, faulting, and igneous activity. Coals of the central and eastern Yentna field have less potential, because they are typically <2 m thick with a high ash content and low calorific value. The remaining coal deposits, in the Little Susitna field, are thin, lenticular, have high ash content, and are marginally lignitic to subbituminous (Sanders, 1981).

Near-surface coals in the Beluga and Sterling Formations of the Kenai Peninsula are typically less mature than coals of the Tyonek Formation in the Susitna lowland; they are characterized by higher ash and volatile contents and a lower fixed carbon content. These lignitic to subbituminous coals are commonly <1 m thick, lenticular, dull, platy, and cleated with abundant preserved wood and bark tissues. However, coal beds as thick as 2 m occur, including one that was mined at Homer (Sanders, 1981). By contrast, numerous coal beds within the Kenai Group (mostly within the Tyonek Formation) of the Susitna lowland are over 9 m thick.

Major coal deposits of the Susitna lowland are dominantly subbituminous B or subbituminous C coal (app. B, table B-5). A thin, steeply dipping coal seam (WC2-9) on Wolverine Creek is ranked as high-volatile-B bituminous coal. Three thin coal seams at Fairview Mountain (FM1-13), Peters Hills (PA1-34), and Talachulitna River (TR1-1; fig. 38) are ranked as subbituminous A coal. Their apparent elevated rank may be due to weathering and oxidation effects.

Table 10. *Total-sulfur and sulfur species of selected coal seams from Susitna Lowland.*

Locale	Sample - seam designation	Sulfur species (%) Organic	Pyritic	Sulfate	Total sulfur (%)
Capps Glacier area	CG4-1	0.23	0.01	0.04	0.28
	CG4-3	-	-	-	0.38
	CG4-4	-	-	-	0.01
	CG4-6	-	-	-	0.01
Fairview Mountain	FM1-2	0.14	0.01	0.06	0.21
	FM1-4	0.24	0.01	0.02	0.27
	FM1-7	0.16	0.02	0.05	0.23
	FM1-10	0.19	0.01	0.01	0.20
	FM1-13	0.23	0.01	0.01	0.24
Peters Hills	PA2-1	-	-	-	0.35
	PA3-1	-	-	-	0.50
	PA3-3	-	-	-	0.64
Wolverine Creek	WC1-3	0.22	0.05	0.39	0.66
	WC1-4	-	-	-	0.67
	WC2-4	-	-	-	0.70
	WC2-9	-	-	-	0.48
	WC2-10	0.17	0.01	0.01	0.19
	WC2-14	-	-	-	0.42

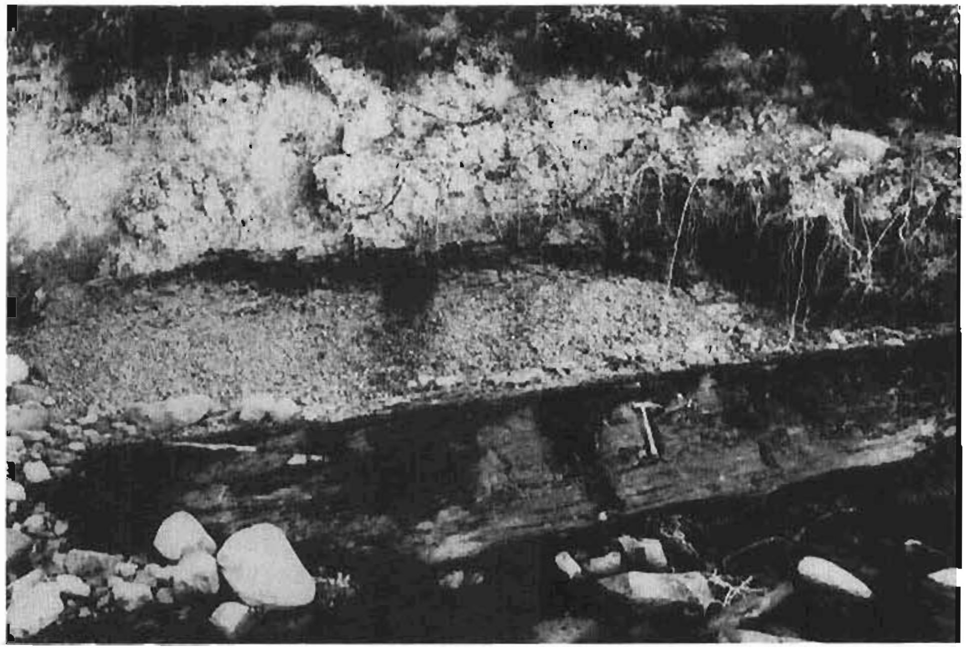


Figure 38. Coal seam (Tertiary, Tyonek Formation) exposed along the Talachulitna River in westcentral Susitna lowland. Photograph by J.E. Sperber, 1981.

Coals are ranked according to the ASTM (1981) classification system. Higher ranked coals are classified according to fixed-carbon and volatile-matter contents as calculated on a dry, mineral-matter-free basis. Lower ranked coals with <69 percent carbon content, as those of the Susitna lowland, are classified according to their calorific value calculated on a moist, mineral-matter-free basis (app. B, tables B-5 and B-6).

Almost all published data on Susitna lowland coal quality (except those industry summaries developed from core samples) were derived from analyses of weathered outcrop samples. Data developed during the present study (summarized here and in app. B) do not meet ASTM criteria for rank evaluation, so conclusions from such analyses should be accepted with caution. Past studies in other areas, however, and a comparison of published data for unweathered samples (tables 11-13) with weathered outcrop samples analyzed during this study, reveal that Btu and vitrinite-reflectance values differ only slightly between weathered Alaskan subbituminous coals and unweathered core samples. Stach and others (1975) reported on the studies of Chandra (1962), who measured and compared reflectances of naturally weathered outcrop samples and fresh, unoxidized samples obtained at greater depths, and found that there was no significant difference in rank, as shown by reflectance measurements of the two sample groups. Although these Susitna lowland evaluations should be viewed as a measure of 'apparent rank,' they nevertheless indicate that lower mean annual temperatures and local relative aridity reduce the effect of oxidation on Alaska coals.

The chief attraction of most Alaska coals is their extremely low sulfur content. Susitna lowland coals contain only 0.3 percent total sulfur (fig. 39; table B-7); the sulfur occurs mainly in organic form (table B-8). Their ash

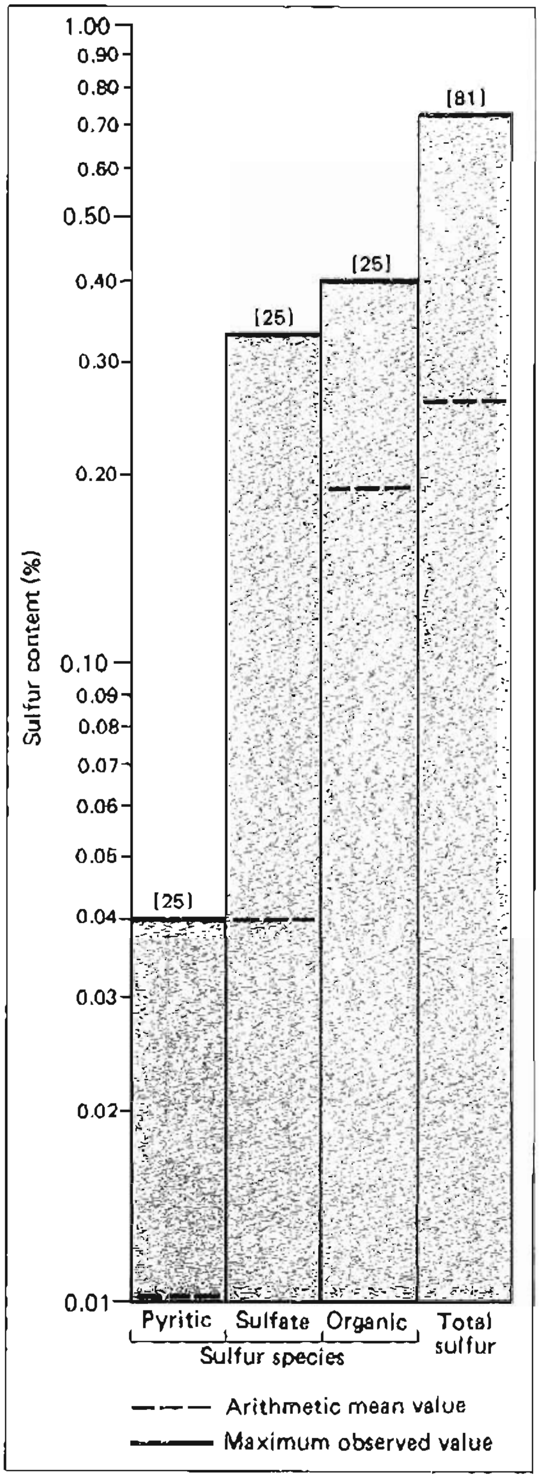


Figure 39. Histogram of maximum observed and arithmetic-mean values, percent total sulfur and sulfur species of analyzed Susitna lowland coal samples. Brackets = number of samples.

Table 11. *Average quality of Beluga field coals (from Patsch, 1976).*

	As received	Dry	Dried to 10% moisture
Moisture (%)	28	--	10
Ash (%)	10	13	12
Volatile matter (%)	32	44	40
Fixed carbon (%)	30	43	38
Sulfur (%)	0.15	0.2	0.2
Heating value			
Btu/lb	7,550	10,500	9,400
Calories/gm	4,194	5,833	5,222

Table 12. *Net coal thicknesses and assay data for major seams, Chuitna River field, Alaska (from Ramsey, 1981).*

Seam	Avg net coal thickness (ft)	Ash (%)	Sulfur (%)	Heating value (Btu/lb)
Brown	28	10.13	0.33	7,845
Yellow	5-15	18.19	0.28	6,782
Green	20	11.25	0.23	7,862
Blue	28	7.34	0.16	8,216
Orange	16	7.99	0.20	8,054
Red	33	7.57	0.17	7,828

Table 13. *Coal-quality data, Johnson Creek and Canyon Creek tracts (from Blumer, 1980). Average for various seams and locations, as-received basis.*

Ash (%)	6-40
Heating value (Btu)	5,400-9,450
Sulfur (%)	0.1-0.2
Moisture (%)	20-30

content varies, but it is low to moderate in some higher quality coals of the Tyonek Formation.

Table 14 shows Barnes' (1966) analyses on several coals from the Beluga-Yentna region. Two coal-bearing sections from the Beluga field (fig. 40) were measured and sampled in 1975 (Conwell, 1977b). Elemental analyses (app. B, tables B-9 through B-14) revealed high levels of sodium, vanadium, and barium, whereas elements such as mercury, antimony, uranium, and thorium, which tend to volatilize during combustion, occurred at low levels.

Table 14. *Analyses of 16 coal samples from Beluga-Yentna region (modified from Barnes, 1966, p. C26-C27). Listed as a range for different parameters analyzed. Rank: Subbituminous B, subbituminous C, and lignite. Calculated moist mineral-free heating value (Btu): 7,650-9,800.*

Sample condition[a]	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulfur (%)	Heating value (Btu)
1	19.7-33.1	30.1-39.9	26.4-40.6	2.0-16.8	0.1-0.4	7,030-9,520
2	-	39.8-56.1	38.0-60.5	2.7-22.2	0.1-0.6	9,470-12,070
3	-	47.2-57.9	42.1-52.8	-	0.1-0.6	11,860-12,600

[a]1 - As received; 2 - Moisture free; 3 - Moisture and ash free.

Table 15 presents published results from proximate and ultimate analyses by Rao and Wolff (1981) of two coal seams: the Waterfall bed, from the Beluga field, and the Sunflower Creek bed, from the Yentna field. Rao and Wolff's (1981) vitrinite-reflectance data (table 16) show that the Waterfall bed is subbituminous and the Sunflower Creek bed is lignitic. The Sunflower Creek bed exhibits a very low ash and very low silica content; most inorganic matter consists of alumina, calcium, magnesium, and iron oxides (app. B, table B-1). Trace elements in Susitna lowland coals were generally similar to those found in other coals. However, some Susitna lowland coals contained higher amounts of barium, manganese, and chromium, and some samples contained lower amounts of arsenic, zinc, boron, lead, and molybdenum (fig. 41). Table B-13 (app. B) lists three-point ash fusibility on two composite coal samples from the Beluga field (Conwell, 1977b). Deformational and melting temperatures reflected low-rank (subbituminous) coals with moderate ash.

DGGS analyzed 66 coal samples from the Susitna lowland (figs. 42 through 45; table 17) using a factor analysis based on proximate coal-quality data and heating values which delineated two significant factors: (1) coals with higher fixed carbon have higher heating values and lower ash; and (2) coals containing higher volatile matter have lower ash. Moisture and sulfur were insignificant factors which explained variances.

Scatter plots of paired proximate variables and heating values revealed similar trends (fig. 43). The high positive correlation in figure 43a supports the direct relationship between heating value and fixed-carbon content: as the fixed-carbon content increased, so did the coal's rank (as measured by heating value). The high positive correlation in figure 43b shows that heating values also varied directly with volatile-matter content. The high negative correlation in figure 43c illustrates an inverse relationship between ash content and fixed carbon; coals with higher fixed-carbon content (higher rank) tended to have lower ash content. The high negative correlation in figure 43d indicates that coals with higher volatile matter had lower ash content. These

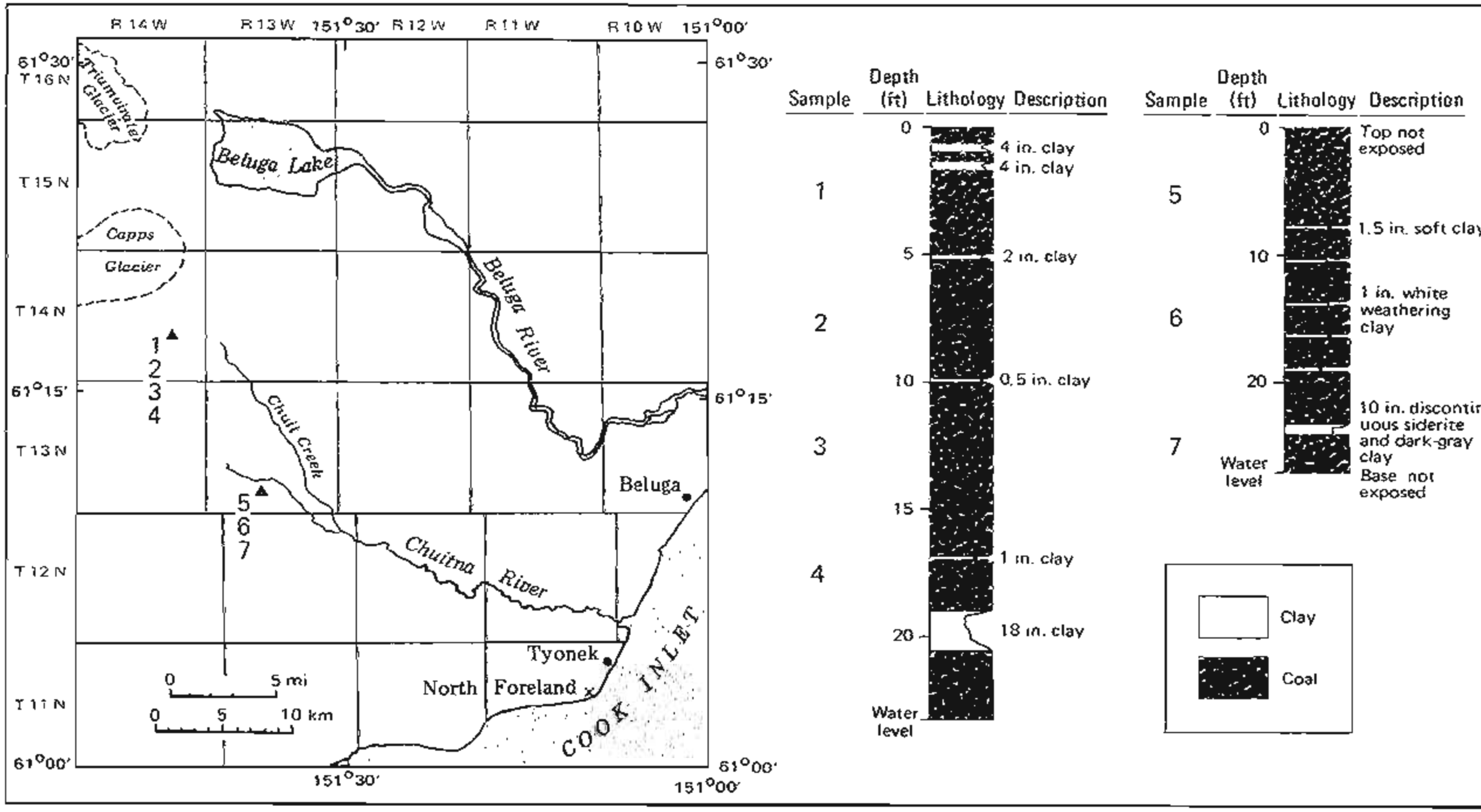


Figure 40. General location and lithologic descriptions of two measured coal-bearing sections (Tertiary, Tyonek Formation) of the Beluga coalfield. Modified from Conwell (1977b).

Table 15. *Proximate and ultimate analyses of raw coals, Waterfall and Sunflower Creek seams (from Rao and Wolff, 1981).*

Coal field, seam	ASTM rank	Thickness, meters (ft)	Sample	Basis[a]	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Heating value (Btu/lb)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Oxygen (%)	Sulfur (%) Pyritic	Sulfur (%) Total
Beluga,	Subbit C	9.1	UA-113	1	23.65	35.20	33.34	7.81	8,327	47.98	6.25	0.54	37.28	0.01	0.14
Waterfall		(30)		2	-	46.10	43.67	10.23	10,907	62.84	4.71	0.71	21.33	0.01	0.18
				3	-	51.35	48.65	-	12,151	70.01	5.25	0.79	23.74	0.01	0.21
Yentna,	Lignite	3.0	UA-115	1	29.80	38.26	28.61	3.33	7,943	45.20	6.76	0.53	44.07	0.01	0.11
Sunflower		(10)		2	-	54.50	40.76	4.74	11,315	64.39	4.87	0.75	25.10	0.01	0.15
(upper)				3	-	57.21	42.79	-	11,879	67.59	5.11	0.79	26.35	0.01	0.16
Yentna,	Lignite	3.0	UA-116	1	29.86	39.29	28.43	2.42	8,017	45.48	6.89	0.49	44.67	0.01	0.05
Sunflower		(10)		2	-	56.02	40.54	3.44	11,429	64.84	5.06	0.70	25.89	0.01	0.07
(lower)				3	-	58.02	41.98	-	11,837	67.16	5.24	0.73	26.79	0.01	0.08

[a]1 - equilibrium-bed moisture; 2 - moisture free; 3 - moisture and ash free.

Table 16. *Vitrinite-reflectance data, Waterfall and Sunflower Creek seams (from Rao and Wolff, 1981).*

Coal field/seam	Sample	Mean maximum reflectance ($\bar{R}o_{max}$)	Frequency V1	V2	Histogram V3	V4
Beluga/Waterfall	UA-113	0.25	3	86	11	0
Yentna/Sunflower (upper)	UA-115	0.33	0	28	66	6
Yentna/Sunflower (lower)	UA-116	0.22	46	37	14	3

relationships are expected for a group of samples which exhibit a narrow range of rank variance, as do most Susitna lowland subbituminous coals. A cluster analysis of Susitna lowland coals (fig. 44) disclosed that coals with similar characteristics formed distinct clusters. Coals from specific localities (Canyon Creek, Beluga River, Saturday Creek) formed fairly close clusters. See table B-14 for a proximate analysis of each sample listed in figure 44.

Results of ultimate-analysis of selected coals from scattered localities in the Susitna lowland (table 18) were typical of subbituminous coals and indicated these coals to be low-rank because of low carbon content and high oxygen content. Lignitic, subbituminous, and low-rank bituminous coals generally contain 5 or 6 percent hydrogen; hydrogen decreases to 3 or 4 percent in high-

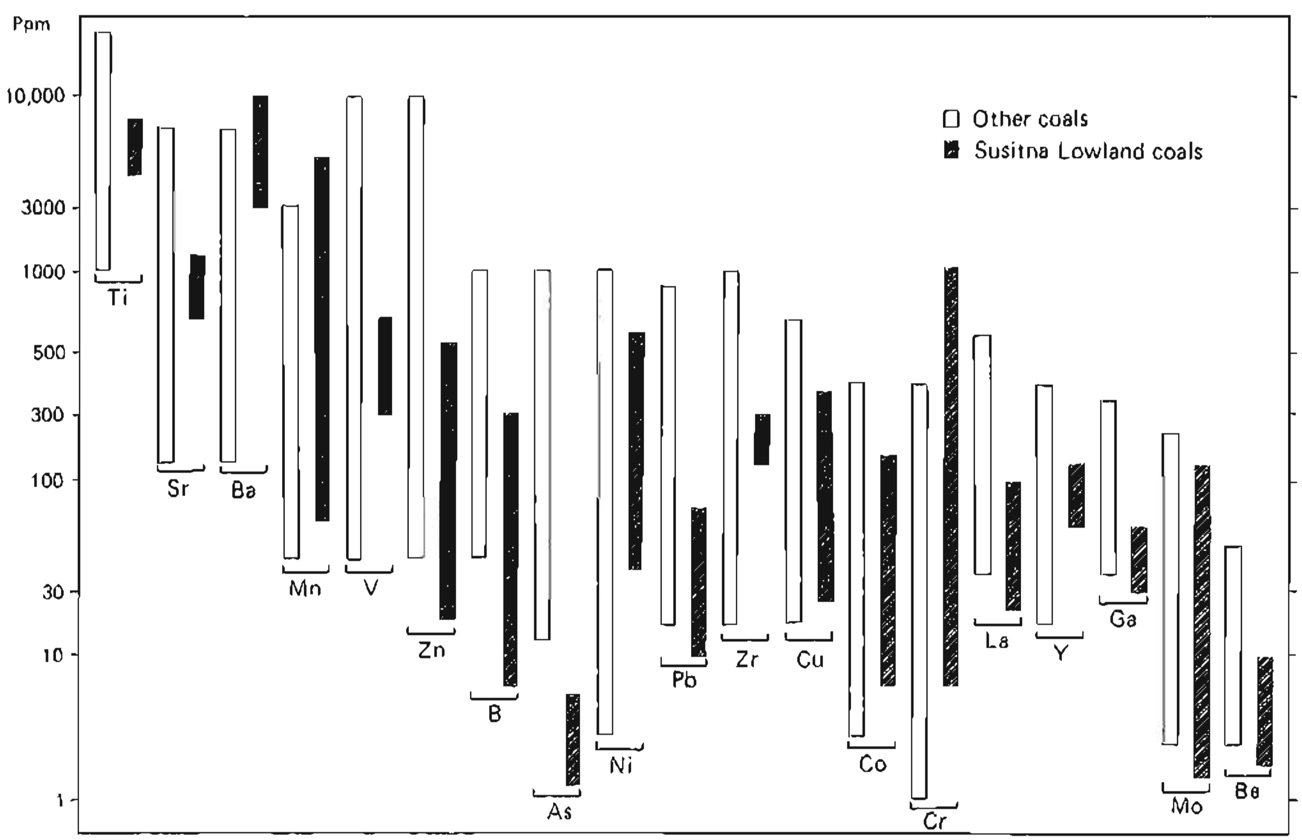


Figure 41. Range of trace elements in raw coal ashes commonly found in other coals compared to range of those in Susitna lowland coals. Data for other coals from Mason (1966, p. 242); Susitna lowland coal data from present study, Conwell (1977b), and Rao and Wolff (1981).

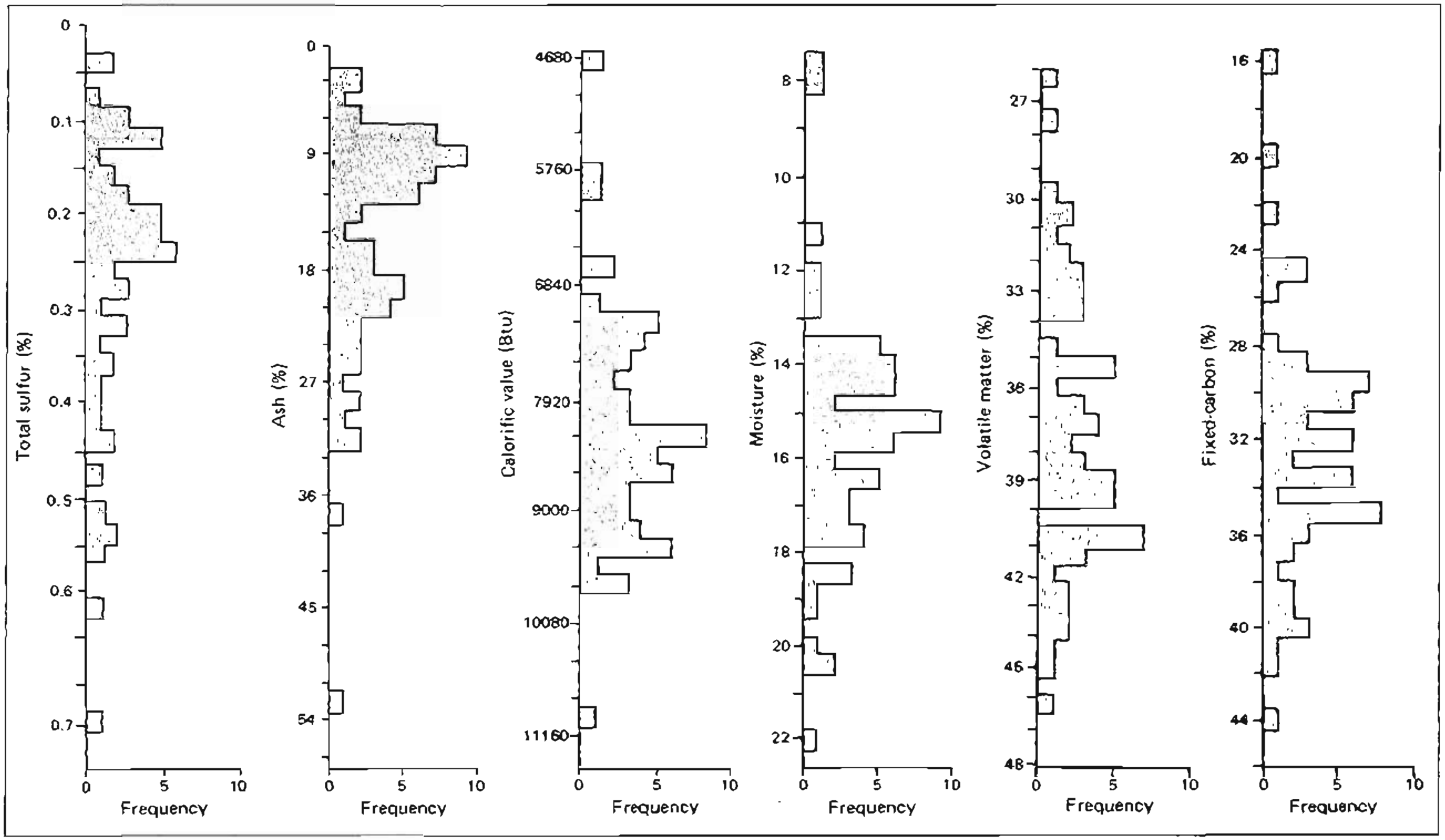


Figure 42. Histograms of various coal-quality parameters of analyzed samples from the Susitna lowland. Frequency indicates the number of samples that exhibit a particular value.

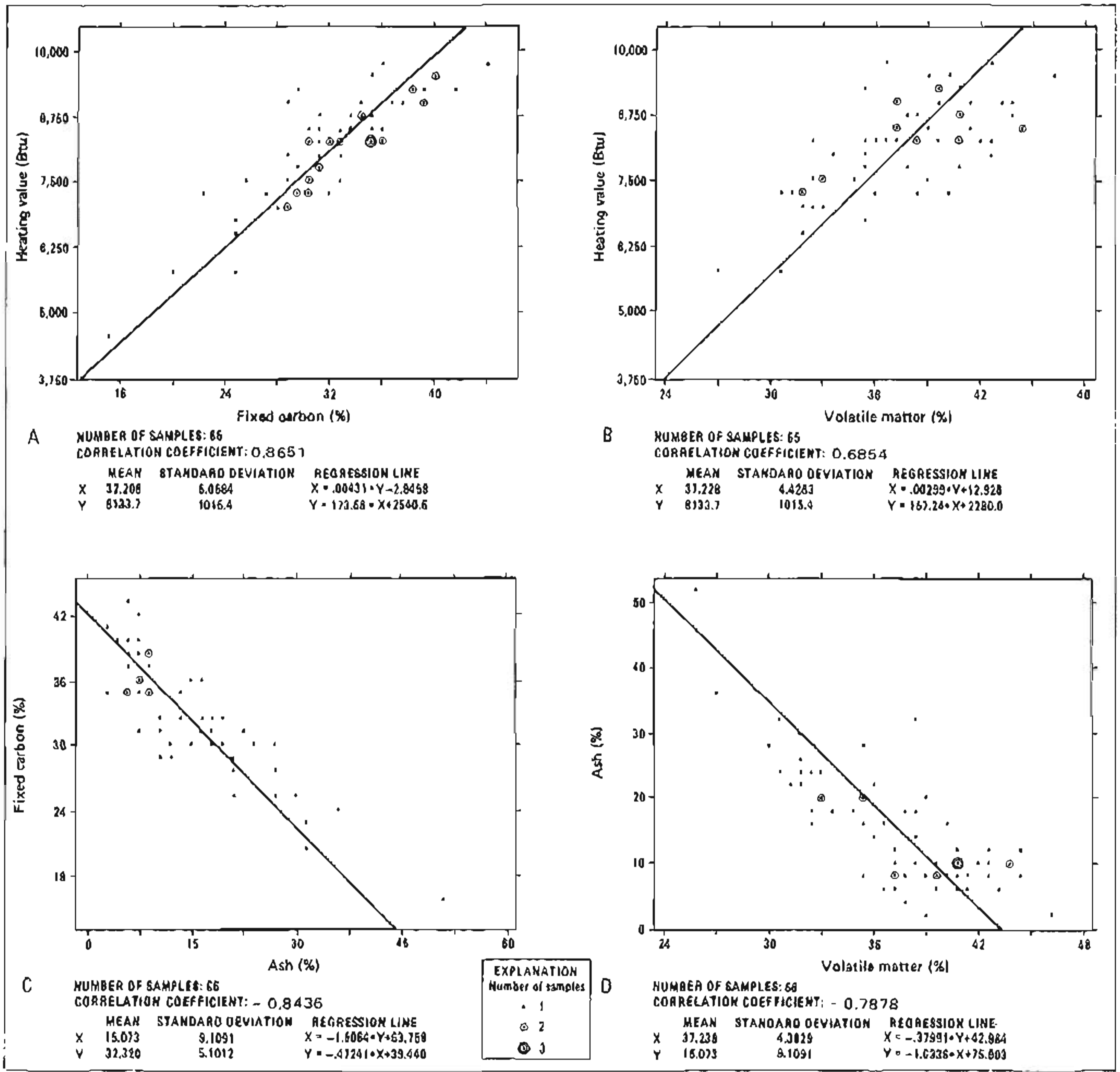


Figure 43. Scatter plots with regression lines of paired proximate variables for analyzed coal samples from the Susitna lowland.

rank bituminous and anthracitic coals. Highest amounts of sulfur and nitrogen usually occur in bituminous coals, decreasing in both lower and higher rank coals. Within the broad spectrum of coal rank, ash contents are typically independent of various rank indicators and reflect variations in the quantity of mineral matter initially deposited in a peat swamp.

Inorganic matter in Susitna lowland coals consisted mainly of silica, alumina, and calcium oxides, with lesser amounts of iron and magnesium oxides (fig. 45). Silica content was highest in Fairview Mountain coal ash and lowest in some Chuitna River coal ash. Alumina content was higher in certain Canyon

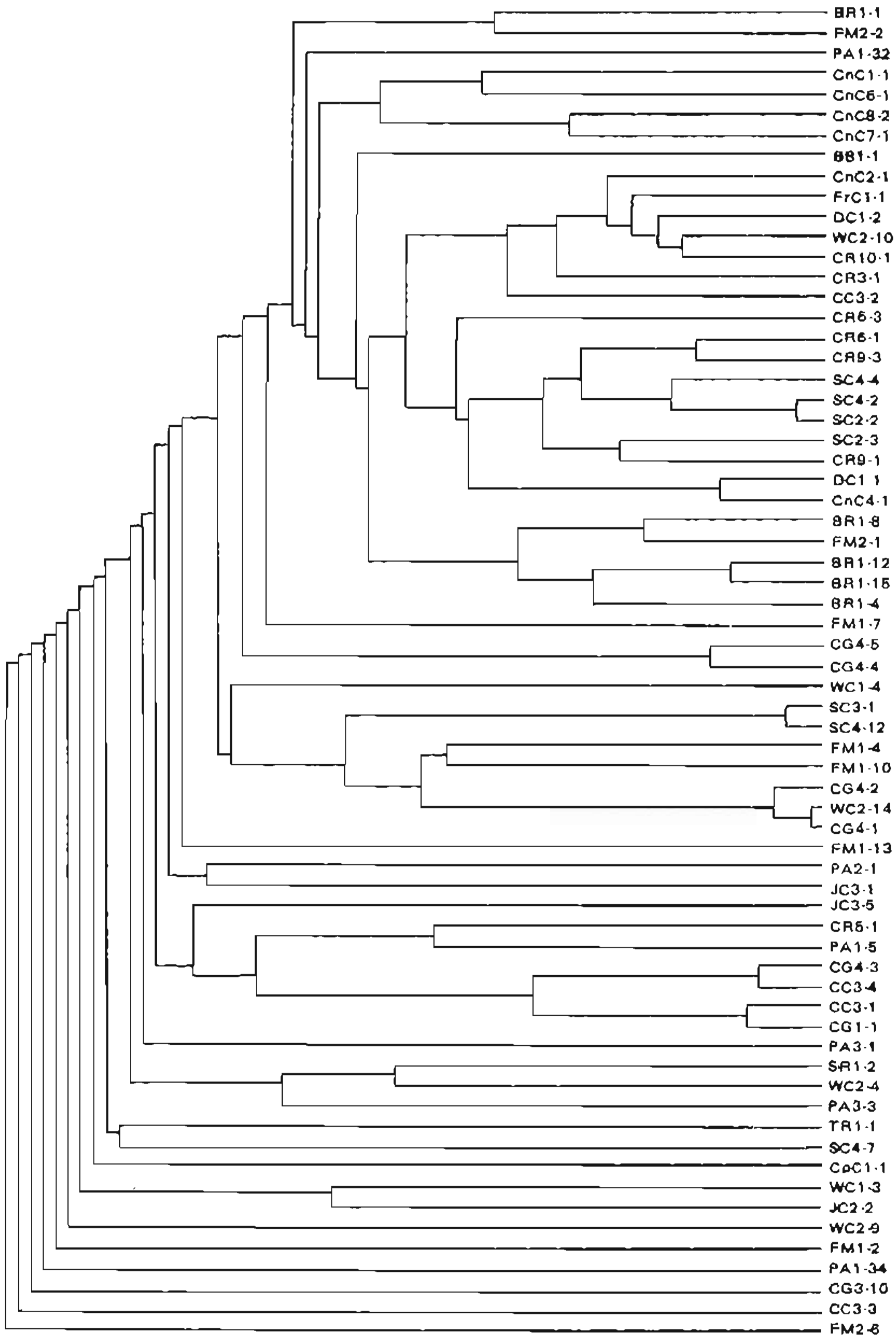


Figure 44. Cluster analysis based on proximate data, total sulfur, and heating values for analyzed coal samples from the Susitna lowland.

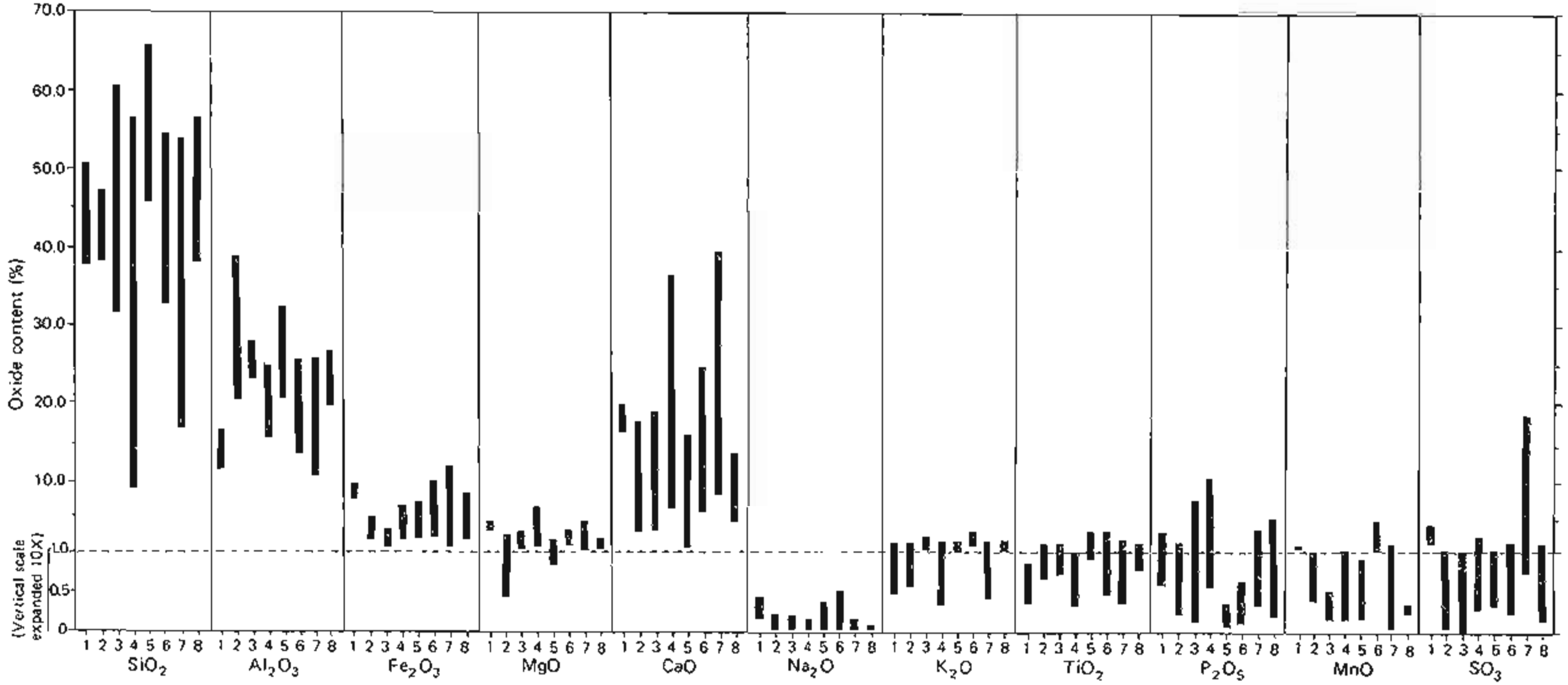


Figure 45. Range of major-oxide concentrations in raw-coal ash from eight localities in the Susitna lowland. Sample locality: 1 = Beluga River; 2 = Canyon Creek; 3 = Capps Glacier; 4 = Chuitna River; 5 = Fairview Mountain; 6 = Peters Hills; 7 = Saturday Creek; and 8 = Wolverine Creek.

Table 17. *Summary of range and mean values and coal-quality characteristics of 66 samples from the Susitna Lowland.*

		Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Sulfur (%)	Ash (%)	Heating value, Btu
	1	7.3-21.9	25.9-46.1	15.1-43.7	0.01-0.73	2.4-51.7	4,570-10,960
Range[a]	2	-	27.9-55.1	16.4-50.9	0.01-0.91	2.8-55.7	4,930-13,400
	3	-	45.6-63.2	36.8-54.4	0.01-1.03	-	10,480-15,540
	1	15.4	37.2	32.3	0.26	15.1	8,163
Mean[a]	2	-	44.1	38.3	0.31	17.7	9,680
	3	-	53.7	46.3	0.39	-	11,766

[a]1 - As received; 2 - Moisture free; 3 - Moisture and ash free.

Table 18. *Result of ultimate analyses, in percent, of selected coals from the Susitna Lowland.*

Sample	Hydrogen			Carbon			Nitrogen			Oxygen			Sulfur			Ash		
	1[a]	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
BR1-1	6.94	6.24	7.18	49.31	57.46	66.10	0.55	0.65	0.74	31.84	22.41	25.80	0.14	0.16	0.18	11.22	13.08	- -
CnC7-1	6.65	5.93	6.41	55.23	64.01	69.24	0.82	0.95	1.02	30.43	21.15	22.89	0.35	0.41	0.44	6.52	7.55	- -
CnC8-2	6.69	5.98	6.64	54.44	63.03	70.04	0.91	1.05	1.17	29.10	19.69	21.89	0.21	0.24	0.26	8.65	10.01	- -
CG3-10	6.08	4.92	7.96	34.48	42.31	68.41	0.53	0.65	1.04	27.62	13.72	22.21	0.19	0.24	0.38	31.10	38.16	- -
CG4-1	6.32	5.43	7.37	42.89	50.71	68.87	0.52	0.62	0.84	27.73	16.59	22.54	0.24	0.28	0.38	22.30	26.37	- -
CR9-3	6.42	5.63	6.41	52.30	60.92	69.26	0.80	0.93	1.06	29.88	20.18	22.94	0.25	0.29	0.33	10.35	12.05	- -
CR10-1	6.43	5.66	7.29	47.16	54.78	70.62	0.73	0.84	1.09	26.28	16.18	20.85	0.10	0.11	0.15	19.30	22.43	- -
FM1-7	6.57	5.86	7.07	48.90	56.48	68.17	0.50	0.58	0.70	28.99	19.70	23.79	0.20	0.23	0.27	14.84	17.15	- -
JC3-1	6.70	5.92	7.22	45.25	53.15	64.83	0.49	0.57	0.70	31.97	22.04	26.89	0.25	0.30	0.36	15.34	18.02	- -
SC3-1	6.58	5.61	7.34	43.52	52.69	68.94	0.56	0.67	0.88	29.66	17.20	22.48	0.22	0.27	0.36	19.46	23.56	- -

[a]1 - As received; 2 - moisture free; 3 - moisture and ash free.

Creek coal ash; Chuitna River and Saturday Creek coal ash tended toward higher calcium-oxide content. Saturday Creek coals also exhibited higher sulfate content. The content of other major oxides was fairly constant at all sites.

In summary, coals of the Tyonek Formation appear to be of higher quality than those of the Beluga and Sterling Formations in the Susitna lowland. This conclusion is supported by results of current coal-characterization research. However, coals from all formations studied were primarily subbituminous with moderate to high moisture, extremely low sulfur, and variable ash.

COAL RESOURCES AND RESERVES

Estimates of Alaska's coal resources and reserves are crude because of insufficient subsurface information over broad areas. Definitive data are needed if the USBM and USGS coal-resource classification system (fig. 46) is to be used. However, until additional drilling and seismic data become available, resource estimates for coalfields in Alaska cannot be precise.

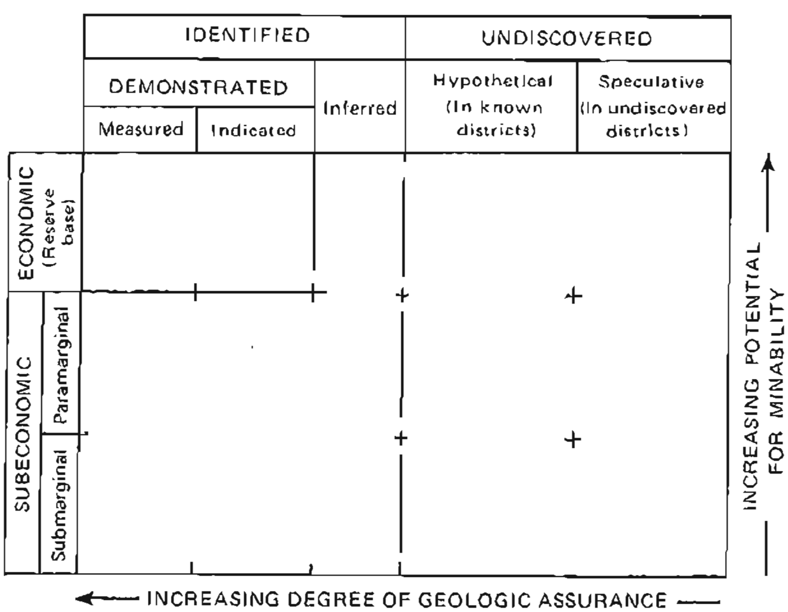


Figure 46. Coal resource classification system of U.S. Bureau of Mines and U.S. Geological Survey. Modified from U.S. Geological Survey (1976).

The Cook Inlet-Susitna lowland area represents the second largest coal resource base in Alaska--surpassed only by the deposits in northern Alaska--and may have the greatest potential of any single undeveloped coal 'property' in the United States. Large areas of the Susitna lowland most likely contain shallow, strippable coal deposits (fig. 47). Sheet 3 is a preliminary interpretative coal-potential map of the Susitna lowland based on the coal-bearing outcrop pattern and geologic structure in the region. Many areas judged to have high potential for coal development have already been leased (fig. 48). However, other large areas in the Susitna lowland probably contain significant but poorly defined or undiscovered coal resources.

The total coal resource in the Cook Inlet-Susitna lowland coal province is estimated at 1.5 trillion tons, 11 billion tons of which are identified resources (McConkey and others, 1977; Sanders, 1981). Estimated identified resources in the Beluga-Yentna region are 10 billion tons; estimated hypothetical resources are 30 billion tons. Swift and others (1980) have estimated that at least 750 million tons are economically minable in about 50,000 ac (20,250 hec) in the Capps and Chuitna districts.

McGee and O'Connor (1975) estimated total resources at 29 billion tons in the Beluga and Yentna coalfields, 24 billion tons on the Kenai Peninsula, and 1.3 trillion tons beneath Cook Inlet (to a depth of 3,050 m). They speculate that 53.2 billion tons of coal lie beneath Cook Inlet in beds thicker than 6 m. Barnes (1967) estimated the identified resources of several major coal seams of the Beluga field (table 19) but did not project the coal beds far from outcrops in valley walls.

Several major coal seams occur on the west of the Susitna lowland in the Yentna coalfield. At Fairview Mountain, six coal beds <2 m thick crop out; a 4.5-m-thick bed is exposed on Camp Creek, a 17-m-thick bed on Sunflower Creek, and several beds <4.5 m thick on Johnson Creek (fig. 49), Nakochna River, and Canyon Creek (sheet 1). At least five seams ranging from 3 to 12 m thick occur on the Johnson Creek tract, and five minable seams from 3 to 14 m thick occur on the Canyon Creek tract. At one locality on Canyon Creek, four separate seams form 19 m of coal in a 23.5-m-thick interval. On the Johnson Creek and Canyon Creek tracts, an identified resource has been estimated to exceed 500 million tons to a depth of 76 m (Blumer, 1981); these tracts are currently leased by Mobil Oil Corporation (see fig. 48).

In the central and eastern Yentna basin, Nelson and Reed (1978) inferred a coal resource of at least 64 million tons. Sanders (1981) stated that coals in this area occur in the upper 2,440 m. The near-surface coals are <1.8 m thick (fig. 50), but placer miners in the Dutch Hills and Peters Hills areas have made use of them for years.

In 1916, Cache Creek Dredging Company began operating the Short Creek Coal Mine on a Yentna River tributary to supply power for its dredge (Naske and Triplehorn, 1980). The Peters Creek coal beds crop out next to the Parks Highway and Alaska Railroad. Portland General Electric drilled in this region in 1976 (table 20).

Coal deposits of the Susitna lowland have been delineated by private industry drilling programs since 1967, but most data are still proprietary.

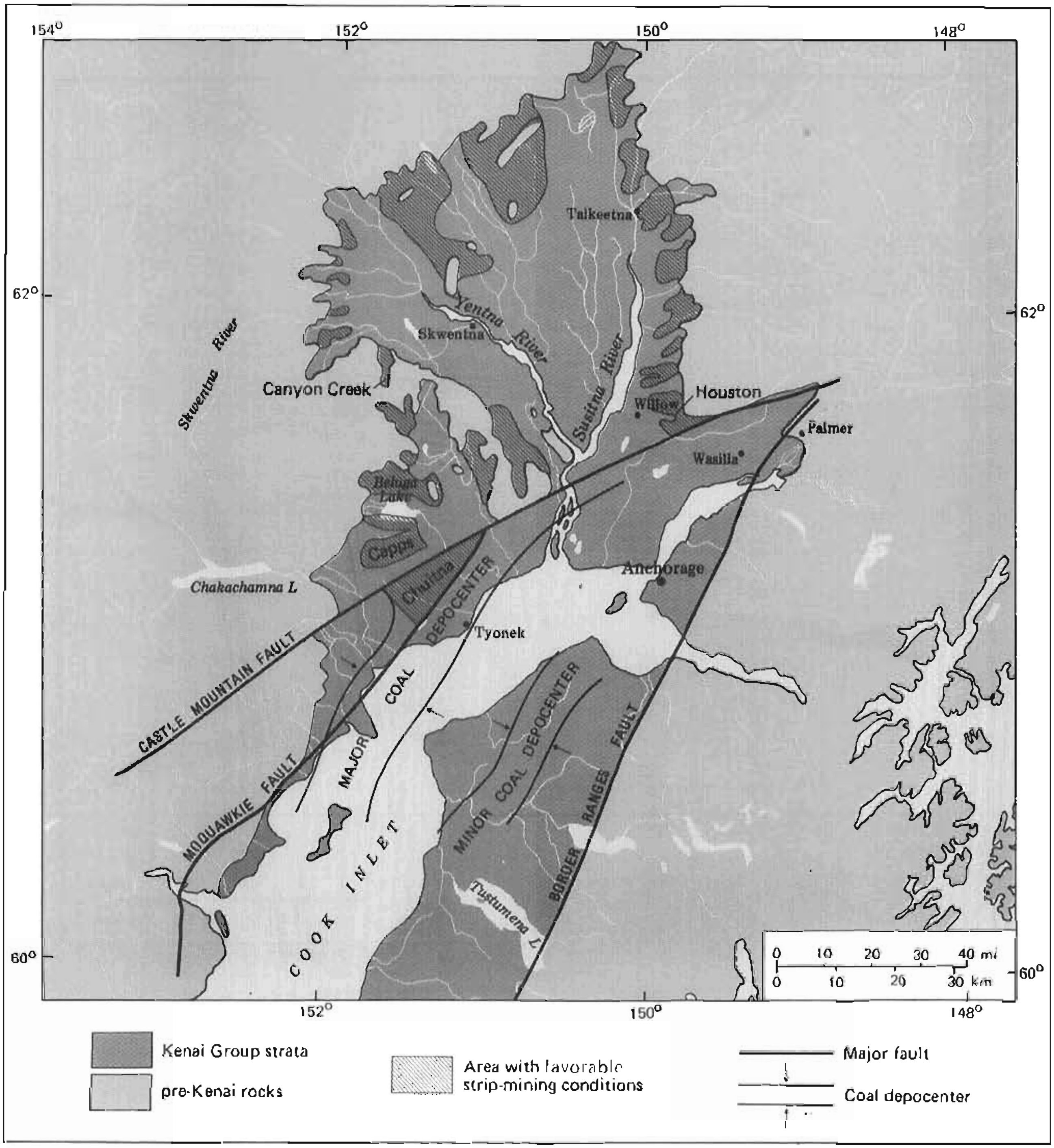
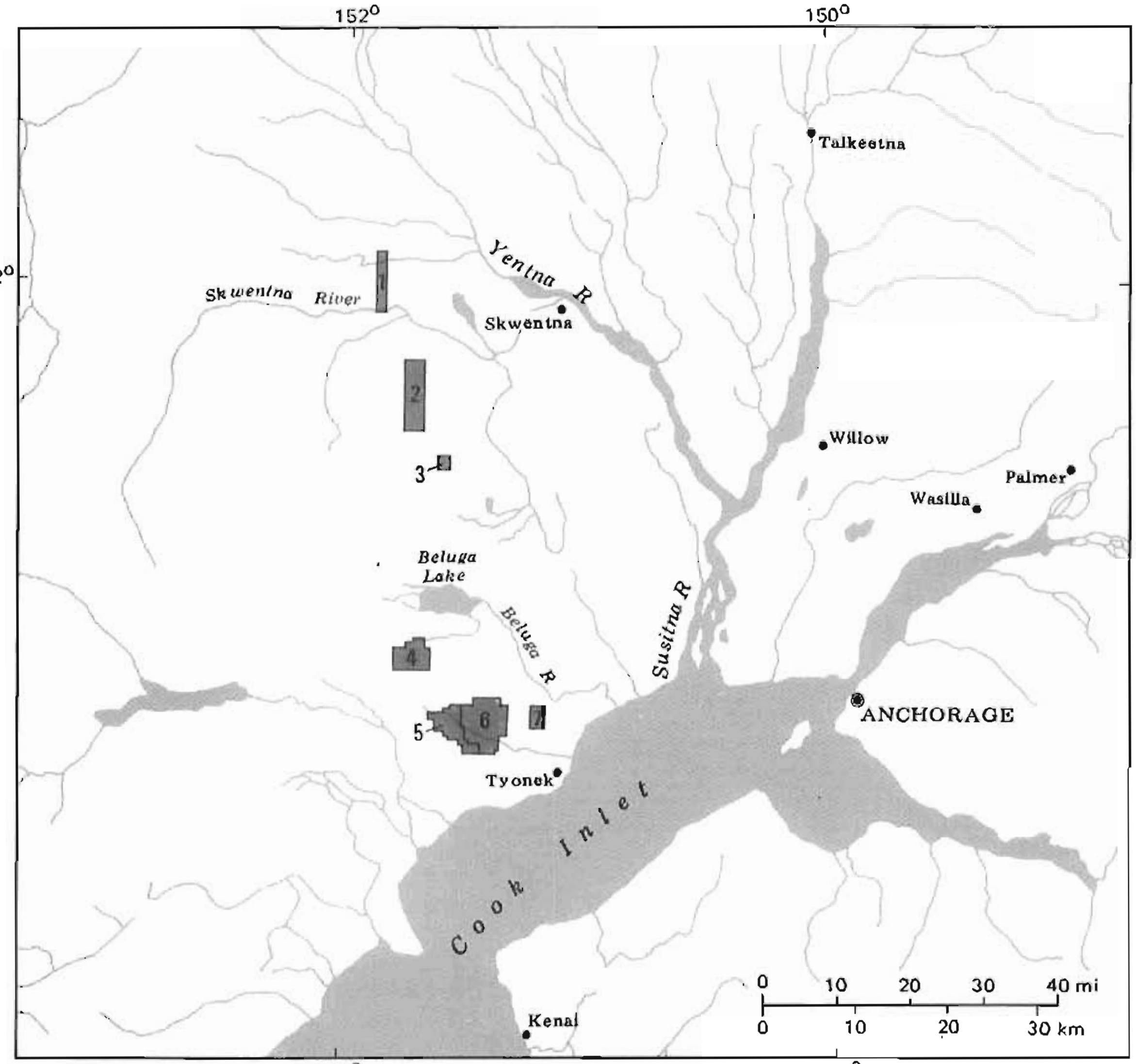


Figure 47. Areas of the Susitna lowland with favorable strip-mining conditions. Modified from Ramsey (1981b).

Current coal lessees have identified several mining sites in the Chuitna district northeast and southwest of the Chuitna River. The combined tonnage of surface-mineable low-sulfur coal held by Placer U.S. Inc. and Diamond Alaska Coal Company is approximately 1 billion tons, with a waste to short ton of coal ratio of <6 bank:yd^3 (table 21).



LOCATION	COMPANY	COAL-LEASE AREA
1	Mobil Oil	Johnson Creek
2	Mobil Oil	Canyon Creek
3	Meadowlark Farms	Friday and Saturday Creeks
4	Beluga Coal	Capps
5	Beluga Coal	Chuitna West
6	Diamond Alaska Coal	Bass, Hunt, Wilson
7	Beluga Coal	Threemile Creek

Figure 48. Locations of major coal leases in the Susitna lowland.

Both companies conducted engineering-feasibility studies for mining 1 to 15 million ton/yr. Placer U.S. Inc. developed and sampled about 500 million tons of mineable reserves in four potential mine sites: one at Capps, two at Chuitna, and one at Threemile (table 21). The Capps deposit, which occupies a localized 11- to 13-km^2 coal basin, contains two major seams, the Capps and

Table 19. *Estimated identified coal resources for several major seams in the Beluga area (from Barnes, 1966).*

Seam	Average thickness (m)	Resources (million tons)
Chuitna bed	16	1,243
Capps bed	15	366
Lower Chuitna bed	<6	69
Canyon bed	7	66
Drill Creek bed	20	64
Beluga bed	9	12

the Waterfall beds, which average 5.2 and 9.2 m thick, respectively. The stripping ratio is estimated at 4:1 to 5:1 (Patsch, 1976).

Six seams constitute most of the resources within the Chuitna River coalfield (table 21). Study of outcrops along the river and a detailed drilling program helped identify the seams. Although the number of mineable seams is similar east and west of the Chuitna River, the coal beds have not been correlated. The Brown coal is Barnes' Chuitna seam; the Red, Orange, and Blue seams were delineated mostly by drilling within a planned open-pit area by Diamond Alaska Coal Company.

Most favorable mining prospects within the Susitna lowland occur where thick coal beds of the Tyonek Formation are within 100 m of the surface. Most coal beds over 6 m thick are restricted to the Tyonek Formation, in which over

Figure 49. A coal bed in the Tyonek Formation exposed along Johnson Creek, western margin of the Susitna lowland. Photograph by J.E. Sperber, 1981.

Figure 50. View of coal-bearing section along Short Creek, Peters Hills area, as seen looking up from creek-bed level (east Yentna field, Tyonek Formation). Photograph by J.L. Sperber, 1981.

Table 20. *Peters Creek drill data.*[a]

Drillhole	Location				Total depth (ft.)	Elevation (ft), top to bottom	No. seams	Coals		
	Quarter-quarter	Section	Township	Range				Max thickness (ft.)	Depth (ft.)	Elevation (ft.)
1	SE¼NE¼	11	26 N	8 W	510	1,150-640	2	1.5	127-175	1,023-975
2	SW¼SW¼	2	26 N	8 W	440	1,165-725	0	-	-	-
3	NW¼NE¼	3	26 N	8 W	460	1,225-765	2	2.0	326-385	899-840
4[b]										
5	SW¼NW¼	14	26 N	8 W	240	1,120-880	2	4.0	64-87	1,056-1,033
6	SE¼SW¼	11	26 N	8 W	510	1,194-684	2	1.0	361-381	833-813
7	NW¼SE¼	11	26 N	8 W	465	1,192-727	2	2.5	323-340	869-852
8	NW¼SW¼	12	26 N	8 W	510	1,157-647	1	2.5	405	752
9	SE¼SW¼	2	26 N	8 W	375	1,175-800	2	3.0	101-353	1,074-822
10	SE¼NW¼	10	26 N	8 W	300	1,340-1,040	0	-	-	-
11	SW¼SE¼	3	26 N	8 W	360	1,200-840	1	4.0	64	1,136
12	NW¼SE¼	13	26 N	8 W	300	1,020-720	0	-	-	-
13	NE¼NE¼	18	26 N	7 W	405	1,000-595	0	-	-	-

[a]Summarized from Portland General Electric information.
[b]Redrilled as DH 6.

Table 21. *Minable reserves, Beluga coal field (modified from Rao and Wolff, 1981). Estimates provided by Beluga Coal Company.*

Basin	Coal beds	Location	Estimate of minable reserves
Threemile Creek	Contains 22 partially exposed, steeply dipping 10-ft-thick seams (avg).	6 mi from Cook Inlet	60 million tons; 9:1 stripping ratio.
Chuitna River	Six seams, two minable outcropping coal beds (one over 40 ft thick).	17 mi from Cook Inlet	200 million tons of near-surface reserves on west side of river.
Capps	Two seams exposed in the Tyonek Formation--the upper Capps bed averages 17 ft thick, the lower Waterfall bed (Capps bed of Barnes, 1966) has an average minable thickness of 30 ft but ranges from 20-60 ft. The interburden thickness varies from 80-280 ft.	26 mi from Cook Inlet	200 million tons in Capps and Waterfall seams at 5:1 stripping ratio.

100 separate beds have been distinguished in a single well log (see fig. 18). Oil-well logs indicate that the West Foreland, Hemlock Conglomerate and Beluga Formations contain several thick coal beds at depth. Coal beds of the Sterling Formation are generally <2.5 m thick. Strata of the Sterling Formation crop out in the northern part of the Yentna field and on the western coast of the southern Kenai Peninsula, where as many as 37 coal beds are exposed. Other major coal deposits occur in the Chickaloon Formation of the Matanuska field. The Chickaloon Formation is up to 915 m thick in the Matanuska field and has at least 30 different coal beds in the upper 460 m (Conwell and others, 1982).

OVERBURDEN CHARACTER

In the absence of active mining operations, the character of overburden of the Kenai Group coals in the Susitna lowland has received little attention. Qualitative and quantitative overburden characterization is significant for several reasons, not the least of which are the enforcement provisions of the Surface Mining Control and Reclamation Act of 1977. The suitability of overburden for use as a subsoil medium during mine site reclamation is of prime importance. The breakup of unweathered rock materials and their placement into the zone of active leaching also creates a potential for deleterious effects on regional surface- and ground-water quality.

The character of overburden varies--as does the quality of individual coal seams within a given basin--and is dependent on its depositional environment. Overburden mineralogy is determined by Eh and pH conditions, temperature, and salinity of the depositional regime.

Pyrite, gypsum, dolomite, and clay minerals within the overburden affect the ground-water chemistry; pyritic and argillaceous materials have the greatest potential for producing highly mineralized ground water. Sulfate (SO_4^{--}) and sodium (Na^+) concentrations are of particular concern (Groenewold and others, 1981). Because of the relatively low content of pyritic sulfur in the coal overburden of southcentral Alaska, weathering of sulfides and subsequent dissolution of sulfates should not significantly impact regional ground-water quality (Merritt, 1982). Nelson (1981) reported relatively high dissolved iron concentrations (0.41 to 6.2 mg/L) and color that ranges from 5 to 200 turbidity units in ground-water samples from five wells between Granite Point and the Beluga River. One sample from a well 14.5 km northeast of Granite Point contained 0.150 mg/L arsenic. Toward the eastern McArthur Flats near Cook Inlet, ground and surface waters are heavily stained with iron and contain reddish-slime deposits, probably formed by iron-fixing bacteria.

Certain elements can sometimes be correlated with a depositional environment: boron, bromine, chlorine, sodium, strontium, phosphorus, nickel, cobalt, vanadium, chromium, uranium, copper, sulfur, carbon, and oxygen are the most common paleoenvironmental indicators, in addition to organic matter (Reineck and Singh, 1975). Bailey (1981) found that relatively higher contents of copper, chromium, titanium, potassium, silicon, and arsenic are associated with fluvial coals; zinc, iron, calcium, pyritic sulfur, and sulfate sulfur are generally more abundant in coals formed in marine-influenced depositional systems.

Overburden is composed of inorganic sedimentary rocks, thin, unmineable coal stringers (rider seams) at the mine site, and unconsolidated profile and bedrock strata. Unconsolidated sequences include soils (topsoil and subsoil horizons), other alluvium and colluvium, and glacial deposits; erratics and well-indurated layers (particularly plastic-clay zones) pose minor problems during mining. Bedrock strata are composed of relatively soft materials such as shale and weathered rock and hard materials (conglomerate, sandstone, siltstone, and limestone). Burn material (baked rock, scoria, or porcellanite) forms varicolored gleys when weathered (fig. 51), and these gleys and melting permafrost may cause slope-instability problems (Schmoll and Yehle, 1978).

Designing a specific program to handle overburden on a mine site may be complicated by rapid lateral or vertical changes in lithology (Merritt, 1983). Where such relationships exist, as in the Susitna lowland, lithologic units may be grouped into several major textural classes or rock types:

- Light-textured materials, predominantly sandstone and sandy siltstone
- Medium-textured materials, predominantly siltstone
- Heavy-textured materials, predominantly claystone
- Coal stringers (including bone coal), rider seams, carbonaceous shales
- Major coal seams
- Interburden (clay or sand partings, including bentonites and tonsteins, in thick coal seams or between coal seams)
- Porcellanite or scoria (baked rock above a burned coal)
- Glacial deposits
- Stream deposits (alluvium)
- Sheetwash colluvium or eolian deposits.

Figure 51. Weathering gleys from burn material in a coal-bearing section of the Tyonek Formation, Chuitna River, Beluga coalfield. Photograph by J.E. Sperber, 1981.

A broad spectrum of overburden characterization analyses was performed on Susitna lowland samples during this study (table 22; app. E, table E-1 through E-9). Although guideline criteria to evaluate the character and quality of overburden have been developed in several other states, including Wyoming and Montana (app. E, tables E-10 and E-11), none have been established for Alaska.

Texture

On a plot of particle sizes and resultant textures for Susitna lowland overburden samples (fig. 52), several samples fell within the 'poor' texture zones. Generally, regraded spoil material that is derived from overburden with high sand (>70 percent), high clay (>40 percent) content, or bouldery surface (as glacial till) may create revegetation problems. High-clay zones produce effective aquicludes; high sand zones exhibit unfavorable moisture-retention qualities; and large boulders create a medium that may contain little fine-grained matrix material and organic matter (Dollhopf and others, 1978). On the basis of unconfined compressive-strength tests of coalfield samples from the Capps district, Chleborad and others (1980; 1982) concluded that the materials ranged from soft soil to soft rock (fig. 53).

During dragline spoiling, overburden with a high clay content can be mixed with overburden with a high or moderate sand content to improve soil

Table 22. *Summary, overburden-characterization analyses of Susitna Lowland samples.*

Parameter		Samples	Locales	Range	Mean
paste pH		88	8	4.1-7.8	6.4
Electrical conductivity		88	8	0.1-0.9 mmhos/cm @ 25°C	0.3 mmhos/cm @ 25°C
Saturation		88	8	24.2-94.1%	52.8%
Saturation	Ca			0.1-6.3 meq/l	1.9 meq/l
extract	Mg	28	3	<0.1-4.4 meq/l	1.3 meq/l
cations	Na			0.4-0.8 meq/l	0.6 meq/l
Sodium adsorption ratio (SAR)		28	3	0.3-2.2	0.6
Exchangeable sodium percentage (ESP)		54	3	0.7-606.4%	16.5%
Particle size		54	3	Variable	. . .
Texture		54	3	Variable	. . .
Organic matter		36	4	0.82-11.89%	4.7%
Lime		36	4	7.7-10.1%	9.9%
Boron (total)		20	2	1.3-100.0 ppm	33.8 ppm
Selenium (total)		20	2	<0.01-0.05 ppm	. . .
Extractable nutrients	NO_3-N			2.1-13.8 ppm	4.0 ppm
	P	43	6	6.85-38.54 ppm	15.44 ppm
	K			47.6-280.4 ppm	136.4 ppm
Ammonium	Ca			2.5-45.4 meq/100g	10.3 meq/100g
acetate	Mg	54	3	0.3-9.0 meq/100g	3.3 meq/100g
extractable	Na			0.6-39.5 meq/100g	1.4 meq/100g
cations	K			<0.1-0.7 meq/100g	0.2 meq/100g
Cation exchange capacity		54	3	1.3-88.4 meg/100g	20.0 meg/100g
Base saturation		54	3	16.7-100.0%	83.4%
Sulfur	SO_4-S			<0.1%	. . .
	Pyritic	28	3	<0.01-0.09%	. . .
	Total			0.00-0.48%	0.07%
Acid potential				0.0-30.0 meq H^+/100g	4.1 meq H^+/100g
Neutralization potential		88	8	3.85-213.84 tons $CaCO_3$ eg./ 1,000 tons	24.2 tons $CaCO_3$ eg./ 1,000 tons
Potential acidity[a]				-5.55-212.89 tons $CaCO_3$ eg./ 1,000 tons	+22.3 tons $CaCO_3$ eg./ 1,000 tons

[a]Positive values indicate excess $CaCO_3$ or basic overburden material.

texture and drainage characteristics in some areas of the Susitna lowland. Dollhopf and others (1978) mixed an overburden sample of 9 percent clay with an overburden sample of 57 percent clay in proportions of 3:1, 1:1, and 1:3, containing 25, 40, and 49 percent clay, respectively, which represented a near-linear relationship. Overburden in the Susitna lowland exhibits abrupt vertical and lateral changes in clay content, which reveals rapid alteration during local depositional processes. Texture can be considerably improved by mixing to dilute the clay content and to produce a more desirable plant-root medium through which water will percolate more easily.

Acidity

Overburden at Fairview Mountain exhibited pH values as low as 4.1 (figs. 54 and 55) and, in at least two samples, deficiencies of ameliorating capacity (over 5 tons $CaCO_3$ equivalent per 1,000 tons of material; fig. 55). However, the highest pyritic-sulfur content of the roof and floor beds of coal seams C through F was <0.06 percent, and highest total sulfur content <0.48 percent (fig. 55). The acidity of the overburden strata probably resulted from biochemical breakdown of organic matter, which ranged from 1.27 to 11.89 percent

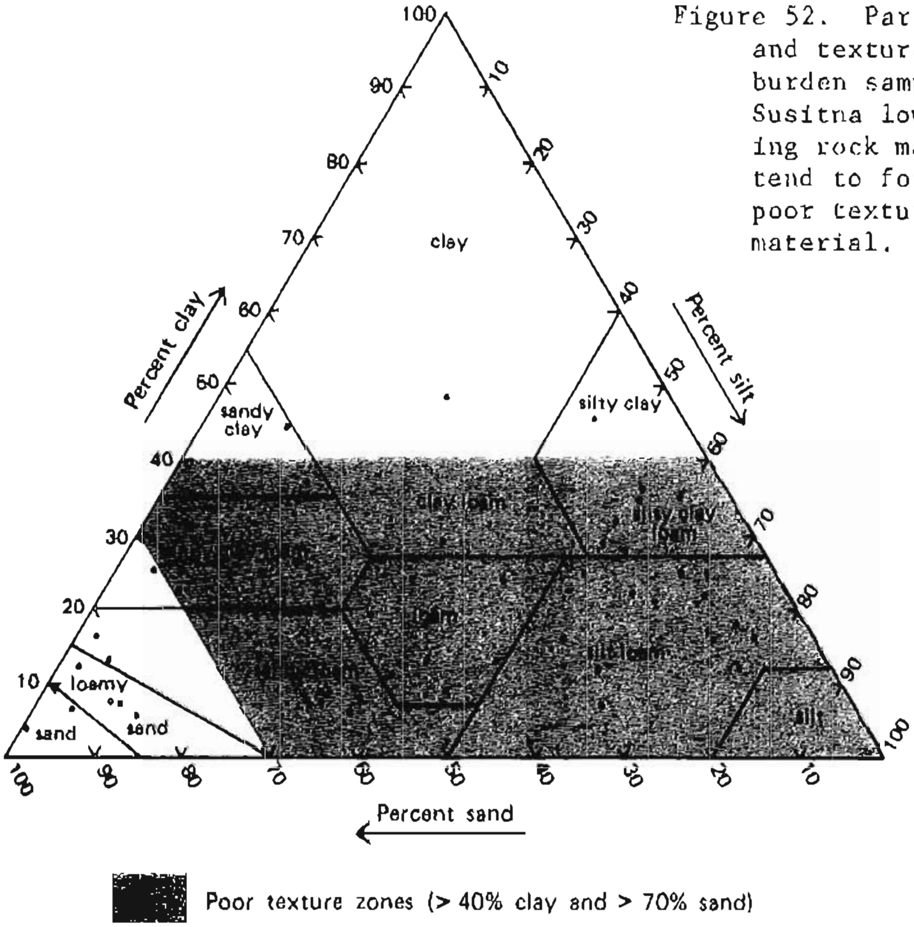


Figure 52. Particle sizes and textures of overburden samples from the Susitna lowland, showing rock materials that tend to form zones of poor texture in spoil material.

in the analyzed samples. Groenewold and others (1981) found that this process often led to higher acidity than did oxidation of disseminated pyrite.

Acidity should not be a significant problem in most areas of southcentral Alaska. However, overburden strata with as little as 0.3 percent sulfur in the form of fine-grained disseminated pyrite (particularly as framboids) can cause acidity and revegetation problems on reclaimed spoil. Pyrite framboids occur in certain Susitna lowland coals (Merritt, 1982); in weathered (oxidized) overburden sequences, soluble sulfate salts may be abundant. The inherent alkalinity level ($CaCO_3$ content) ameliorates existing acidity.

Saline-sodic spoil

Although materials characterized by excess soluble salts and a high level of adsorbed sodium are common in the arid to semiarid regions of the western United States, analytical results of this study supported the conclusion of Mitchell and others (1981) that saline and sodic spoil should not be a major problem in Alaska coal basins. They found no zones of salt accumulation and no sodium-adsorption levels that would be detrimental to plant growth in the materials they examined from the Usibelli Mine at Healy, the Capps district of the Beluga field, an abandoned strip mine in Matanuska Valley near Sutton, and an abandoned site at Meade River. Electrical conductivities in Susitna lowland

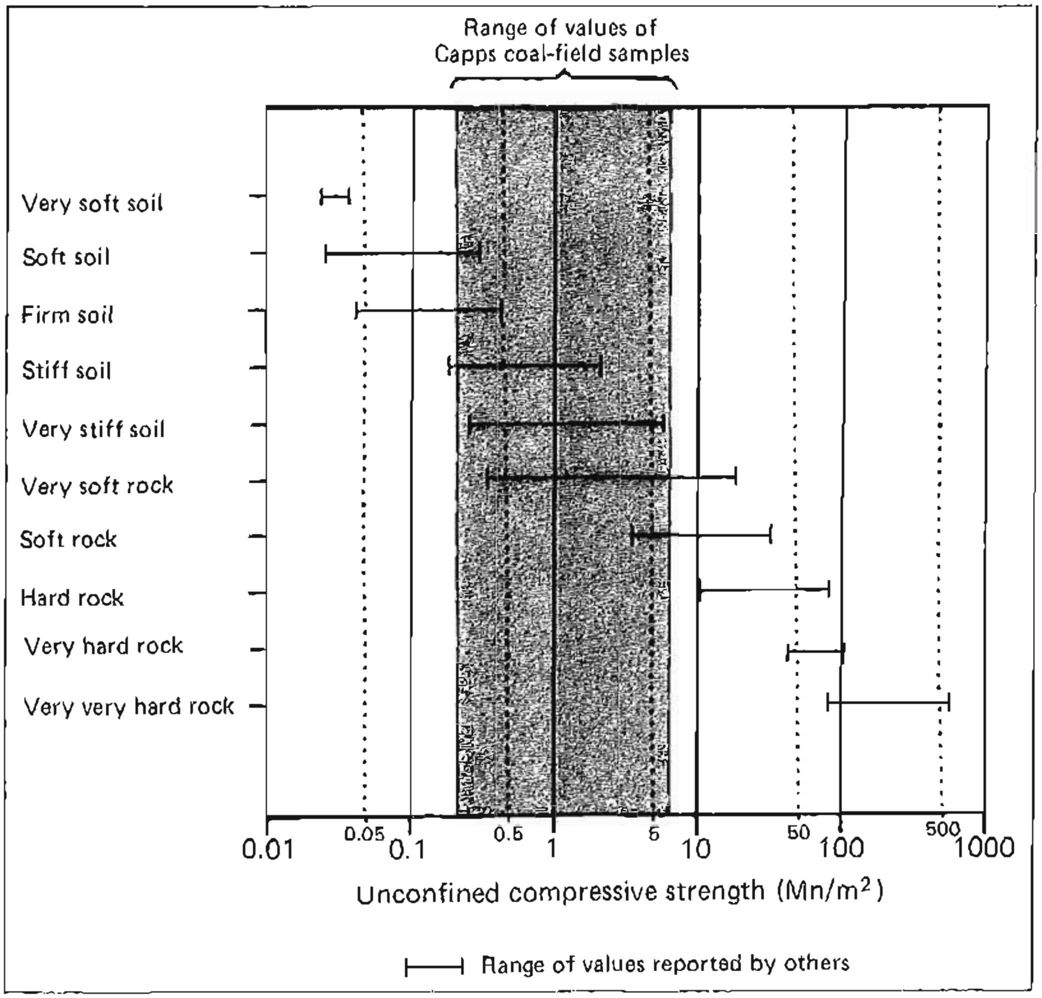


Figure 53. Range of unconfined compressive strength for Capps area coal samples. Modified from Chleborad and others (1980, 1982).

samples analyzed in this study ranged from 0.1 to 0.9 mmhos/cm at 25°C, and the mean sodium-adsorption ratio was <1.0. Although a few samples exhibited anomalously high exchangeable-sodium percentages, the mean value (tables 22 and 23) was 16.5 percent .

Cation-exchange capacity

The 54 overburden samples analyzed from three sites in the Susitna lowland ranged from 1.3 to 88.4 mEq/100 g, with a mean of 20.0 mEq/100 g. Shale and mudstone generally had relatively high cation-exchange capacities (CEC), which indicates the presence of montmorillonite and availability of adequate plant nutrients for use as a subsoil medium. The CEC in sandstones rarely exceeded 5 mEq/100 g unless the sandstone was argillaceous.

Trace elements

Few baseline data exist to establish acceptable trace-element levels in overburden, particularly in Alaska. Hinckley and others (1982) concluded that

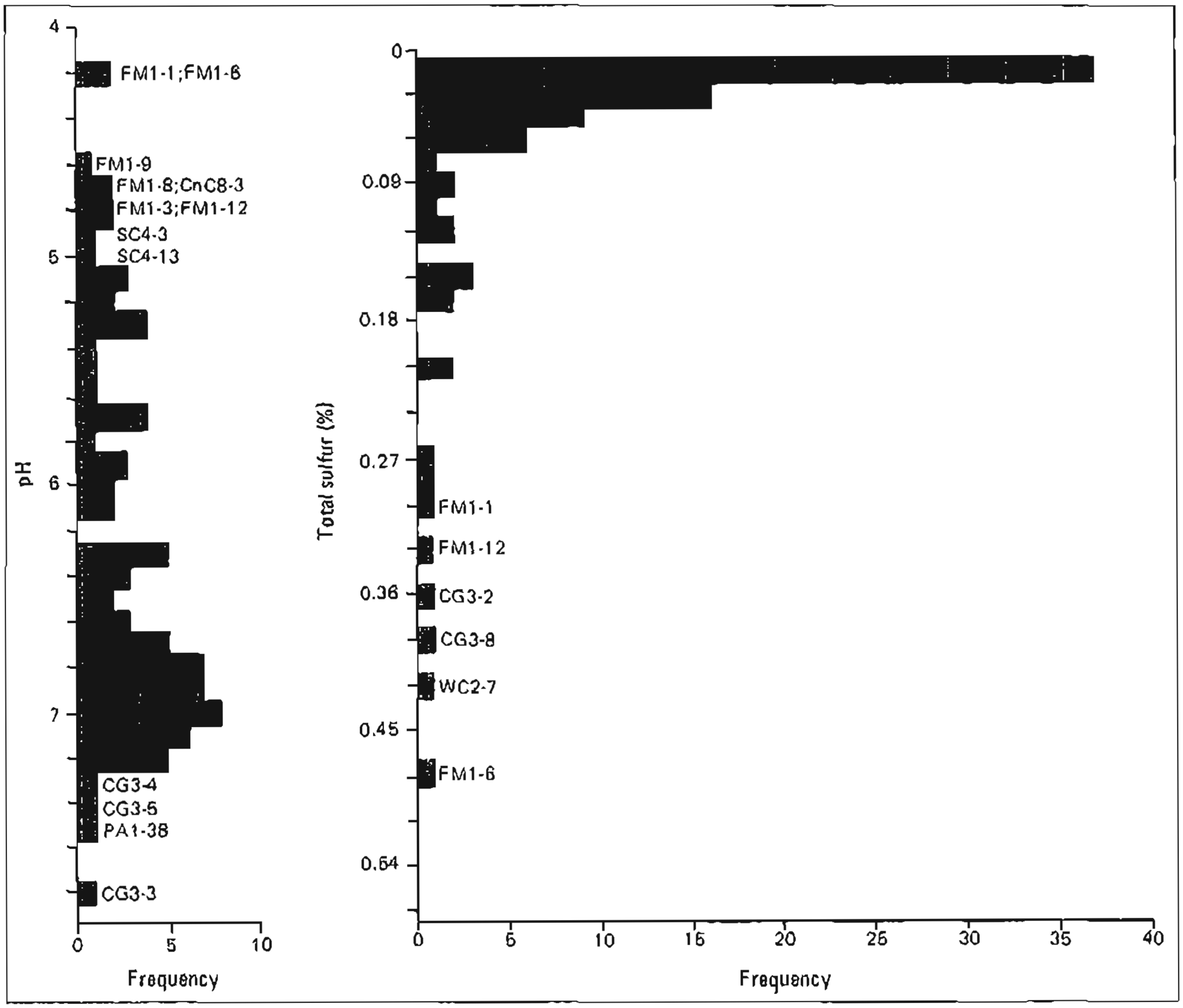
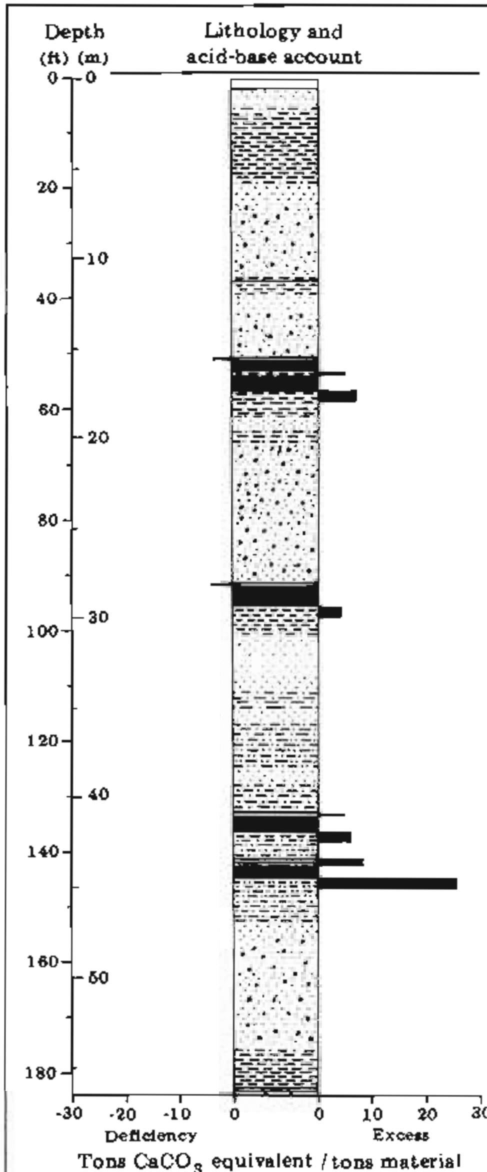


Figure 54. Histograms of pH and total-sulfur content for overburden samples from the Susitna lowland. Frequency expresses number of samples exhibiting a particular value. Samples having extreme values are designated by sample code (see apps. C and E).

considerable variation occurs in rock chemistry and depositional environments over short distances in the Beluga coal area and fine-grained rocks (claystone) typically contain at least twice the amount of trace elements that coarse-grained rocks (sandstones) do (table 24). Overburden samples from several localities in the Susitna lowland (Beluga River, Capps Glacier, Fairview Mountain, Peters Hills area, Saturday Creek, and Wolverine Creek) revealed significantly higher levels of trace elements such as lead, zinc, nickel, cobalt, and cadmium than those recommended for prime topsoil or subsoil media (fig. 56).

The maximum selenium content of 20 samples from two Susitna lowland sites (table 22) was well below the toxicity threshold level of 2 ppm, but total-boron content indicated excess boron concentrations (>5 ppm) in mine



Sample number	Coal-seam designation	Description	Paste pH	Sulfur (%) Pyritic / total	Lime (%)	Organic matter (%)
FM1-1	F Seam	Roof: carbonaceous shale	4.1	0.06 / 0.30	10.0	9.46
FM1-3		Parting: carbonaceous claystone	4.8	0.02 / 0.06	9.8	6.10
FM1-5		Seatrock: claystone	5.1	0.01 / 0.02	9.9	1.59
FM1-6	E Seam	Roof: carbonaceous shale	4.2	0.01 / 0.48	9.0	8.63
FM1-8		Seatrock: claystone	4.7	0.02 / 0.02	10.0	2.32
FM1-9	D Seam	Roof: carbonaceous shale	4.6	0.01 / 0.14	9.3	11.89
FM1-11		Seatrock: claystone	5.1	0.01 / 0.01	9.9	1.27
FM1-12	C Seam	Roof: carbonaceous shale	4.8	0.04 / 0.32	8.2	9.56
FM1-14		Seatrock: sandy claystone	7.2	0.04 / 0.04	10.1	1.94

Figure 55. Overburden-interburden characteristics for a coal-bearing section from Fairview Mountain, Tyonek Formation, northwest Yentna field.

Table 23. *Geochemical parameters measured in determining the levels of soluble salts and sodium in soils and overburden.*

Parameter	Characteristics
Conductivity (EC)	Directly related to soil salinity. Conductivities over 16 mmhos/cm at 25°C generally rated as unsuitable, and from 8 to 16 mmhos/cm at 25°C as poor (table D10).
Saturation percentage (SP)	Moisture content of a given material at its point of saturation. High saturation (>80%) can often be correlated with high clay strata.
Saturation extract cations	
Sodium (Na^{+})	Tends to disperse clay materials, hence reducing aeration and soil hydraulic conductivity. Adverse structural modification to a soil is usually due to excess sodium concentrations.
Calcium (Ca^{++})	Directly affects the drainage and leaching of soils; results in a sodic condition.
Magnesium (Mg^{++})	Low magnesium levels can reduce the concentrations of phosphorous. High levels of calcium ions may alleviate toxic reactions of plants with high concentrations of magnesium (U.S. Department of Agriculture, 1954).
Sodium adsorption ratio (SAR)	Determined from the modified Gapon equation: $SAR = Na/\sqrt{(Ca + Mg)/2}$. A material with an SAR value above 15 is judged unsuitable as a plant root-zone medium (Sandoval and Gould, 1978).
Exchangeable sodium percentage (ESP)	Defines the extent to which the adsorption complex of a soil is occupied by sodium. High-clay materials usually have attendant high exchangeable sodium contents and an SAR value above 10 (Sandoval and Gould, 1978). Soils with high ESPs (>15%) and high SARs tend to have serious physical problems, resulting in low hydraulic conductivity, poor aeration, and reduced productivity.

spoil that could be a problem for revegetation. Molybdenum concentrations in all Susitna lowland overburden samples analyzed were <15 ppm; at this level, molybdenum may be concentrated in plant tissues and cause molybdenosis in grazing ruminants. Lead content in the overburden samples ranged to about 50 ppm; generally, materials with lead levels higher than 10 ppm should be selectively handled.

Dollhopf and others (1978) cited an example of mixing inhabitory strata (lead concentration 15 ppm) with overburden strata (lead concentration 1 ppm), which resulted in a spoil-pile concentration of between 3 and 5 ppm lead. If left near the reclaimed surface, concentrations at this level would not harm plant growth. Scattering spoil material through the dragline swing cycle, rather than dumping it at the end of the cycle, results in a more chemically and physically homogeneous and environmentally acceptable spoil medium.

Macronutrients and micronutrients

Extractable-nutrient levels were analyzed in 43 overburden samples from six sites in the Susitna lowland (table 22). Results indicated that the samples were deficient in the major plant nutrients nitrogen and phosphorus (and sometimes potassium); these nutrients would have to be added if the overburden

Table 24. *Geometric means (ppm) for certain trace-element contents in overburden samples from the Susitna Lowland (present study), Capps coal field, and suites from other areas in the conterminous United States (Hinckley and others, 1982).*

Trace element	Rock type[a]	Susitna Lowland overburden	Capps field overburden, Beluga area, 1979	Capps field overburden, Beluga area, 1980	Ft. Union Fm overburden	Kimbeto, N.M. overburden	Cretaceous overburden suite	San Juan Basin Topsoils	San Juan Basin Minesoils
Boron	1	22	17	--	42	13	14	7	13
	2	37	26	--	59	19	28		
Chromium	1	--	35	39	46	19	16	22	14
	2	--	61	70	72	30	43		
Cobalt	1	12	7	6	11	8	4	6	9
	2	16	9	8	9	12	9		
Copper	1	28	11	23	14	14	7	10	18
	2	51	40	43	38	39	30		
Lead	1	15	11	22	12	10	6	11	11
	2	26	20	37	11	16	13		
Manganese	1	761	167	412	233	183	75	260	340
	2	804	302	303	300	105	209		
Molybdenum	1	<10	2	--	2	2	2	2	3
	2	<10	2	--	6	3	2		
Nickel	1	26	23	24	26	12	10	9	12
	2	52	36	38	30	23	27		
Vanadium	1	--	60	71	75	60	37	45	56
	2	--	119	117	86	90	91		
Yttrium	1	--	17	15	30	26	19	27	32
	2	--	28	21	19	33	30		
Zinc	1	60	61	102	62	61	35	48	56
	2	100	108	143	59	80	105		

[a]1--Coarse grained (sandstones)
2--Fine grained (claystones).

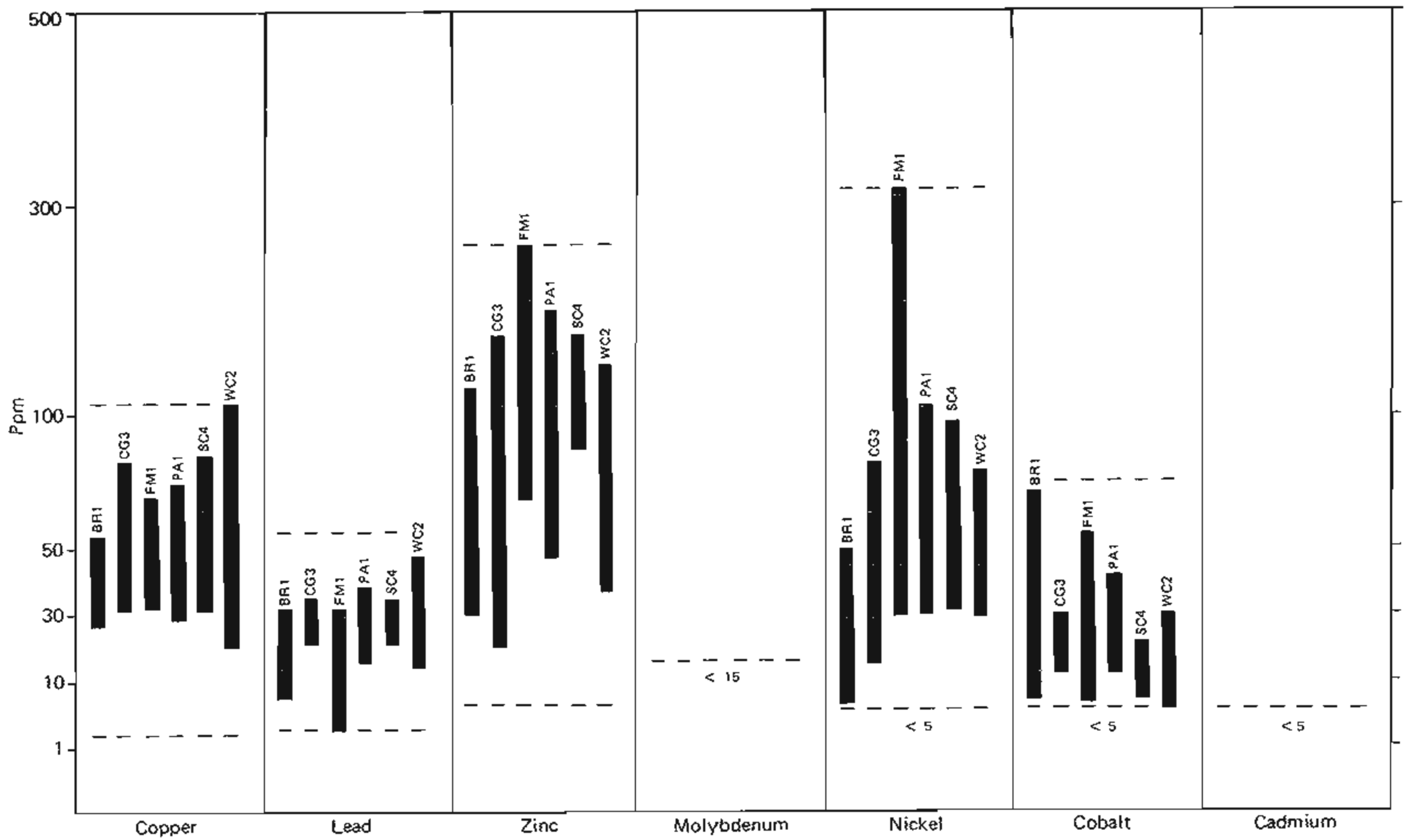


Figure 56. Range of certain trace elements in overburden materials at six sites in the Susitna lowland. BR = Beluga River, CG = Capps Glacier area, FM = Fairview Mountain, PA = Peters Hills area, SC = Saturday Creek, and WC = Wolverine Creek.

were to be used as a subsoil medium. The overburden material was not deficient in the common micronutrients (iron, manganese, zinc, boron, molybdenum, and copper) although zinc, boron, molybdenum, and manganese levels in some samples may point to a potential problem with metal phytotoxicity.

In summary, coal overburden evaluations of the Susitna lowland samples yielded six main results: (1) poor texture zones can occur in regraded spoil materials that will cause drainage and revegetation problems; (2) any acidity problems will be minor and localized; (3) the potential for development of saline-sodic soil conditions is low; (4) toxic levels can result locally from certain trace elements such as boron, molybdenum, and lead in spoil materials; (5) positive growth response can be expected when macronutrients nitrogen and phosphorus are added; and (6) certain micronutrients (zinc, boron, molybdenum, and manganese) are not deficient but can cause problems of local metal phytotoxicity.

CONCLUSIONS

The Tertiary Kenai Group of the Susitna lowland in southcentral Alaska contains substantial reserves of subbituminous coal suitable for surface mining. Most coal resources occupy a crescent-shaped belt along the western and southern margin of the Susitna lowland. Although estimates of resources and reserves vary significantly, total mineable reserves amount to several billion tons. These coals are especially attractive because of their extremely low sulfur content and their proximity to prospective Pacific Rim markets.

The coals are generally comparable in quality with those of the Powder River basin in the western U.S. Calorific and mean-maximum-reflectance values indicate that most Susitna lowland coals are of subbituminous rank.

Although the coals are laterally discontinuous and sometimes high in ash content, the numerous seams--particularly within the Tyonek Formation--and the geochemical and physical character of the enclosing strata make several coalfields economically attractive. Subsurface information is, unfortunately, scant, and the true extent of these deposits is unknown.

Petrologic studies indicate that most Susitna lowland coals originated in forest-moor environments within the telmatic zone. Northern Yentna field coals (upper Tyonek and Sterling Formations) probably originated in a drier paleoenvironment (perhaps in the terrestrial zone) from tree-vegetation peats.

Overburden is low in sulfur (<0.5 percent), which occurs mainly in the organic form. Acidity and high levels of soluble salts and adsorbed sodium do not appear to constitute major problems. Isolated acid conditions, however, can develop, and levels of certain trace elements in overburden materials, regraded spoils, and surface and ground waters should be monitored. Textures in the regraded-spoil profile can pose drainage and revegetation problems.

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APPENDIX A
General Description of Coal Outcrops

Table A1. *Coal locales.*

Locale no.	Location	Code	Outcrop-section thickness	No. of coal beds	Maximum coal-bed thickness	Dip	General comments
1	Beluga River	BR	Approximately 150 ft described	Over 12 observed; 7 described in section	10 ft	35°	Numerous seams exposed laterally along river. Coals appear to be subbituminous; predominantly dull, blocky, and hard; locally platy and bony. Thicker seams near basal part of section have thin claystone partings. Underclays typically medium-gray sandy claystones. Sand content generally increases upward in the section. See app. C for description of coal-bearing section.
2	Beshta Bay	BB	80 ft	1	5 ft	30°	Dull, blocky coal with occasional thin vitrain bands; seam exposed along coast in 10-mi long beachcrop of Beluga Formation. Overburden and seatrock consist predominantly of pebble sandstone and conglomerate, sandstone, light brown, medium grained, locally clayey. Top of section contains very large boulders up to several feet in diameter.
3	Camp Creek (Fairview Mtn area)	CpC	20 ft	1	15 ft exposed	37°	Predominantly dull, platy coal, becoming blocky toward basal portion; locally, bony. Highly weathered on surface outcrop. Exposed for about 200 ft along Camp Creek. Overburden and seatrock not exposed
4	Canyon Creek	CnC1	Approximately 150 ft, only part of section described	1	14 ft	40°	Predominantly dull, blocky coal, but with abundant thin vitrain bands. Isolated block of Tertiary Kenai Group strata. Gravel (with cobbles generally <1 ft diam) covers overburden section.
5	Canyon Creek	CnC2	20 ft exposed	1	10 ft	35° where bedded, locally contorted	Thermally altered(?) bed locally severely contorted because of structural deformation. Rim of highly oxidized ironstone (hematite) forms aureole because of effects of natural burning of coal bed.
6	Canyon Creek	CnC3	...	...	...	...	Gradational zones of burn that include light-gray baked claystone with abundant plant fossils; cream-colored baked claystone; pink to light-red scoriaceous clinker with abundant hematite; and dark-red to maroon burn (pure hematite, locally specular).
7	Canyon Creek	CnC4	60-80 ft	1	Over 20 ft	Slight dip	Site about 50 yd south of large burn area at CnC3. Coal locally appears thermally altered (bright, vitreous, with conchoidal fracture). Large talus slope beneath coal prevents exact determination of thickness and sampling of seatrock.
8	Canyon Creek	CnC5	50 ft exposed	1	About 20 ft exposed	15°	Locale is just south of CnC1. Good exposure of seatrock. See app. C for description of coal-bearing section.
9	Canyon Creek	CnC6	Only 10-15 ft to first terrace above stream	1	6 ft exposed to creek level	Nearly horizontal	Seam extends below stream. Locally, slightly slumped. Roof and floor not exposed.
10	Canyon Creek	CnC7	25 ft	1	10 ft	Steep	Surface-weathering pattern on coal very distinctive. Possible volcanic-ash parting (tonstein). See app. C for description of coal-bearing section.
11	Canyon Creek	CnC8	Varies laterally	1	14 ft	Strong	Complete seam thickness exposed with claystone overburden and seatrock. Quality of seam deteriorates noticeably in basal 2-3 ft. See app. C for description of coal-bearing section.
12	Capps Glacier area	CG1	Approximately 25 ft exposed and accessible	2 beds, Waterfall and Capps beds; only Waterfall accessible	Top 6 ft exposed	10°	Capps and Waterfall beds exposed across valley. Area heavily vegetated and largely inaccessible. Seatrock is claystone: medium gray, sandy, firm, breaks in conchoidal blocks, with local yellow to orange goethitic staining.
13	Capps Glacier area	CG2	25 ft	...	...	...	Section underlying Capps bed includes iron-oxide-stained, coarse-grained sandstone with interlayered hematite bands and medium-gray, medium-grained hard sandstone.

Table A1. *Coal locales* (cont.)

Locale no.	Location	Code	Outcrop-section thickness	No. of coal beds	Maximum coal-bed thickness	Dip	General comments
14	Capps Glacier area	CG3	30 ft	1, Capps bed	Top 6 ft exposed	3°	Overburden strata includes predominantly medium- to dark-gray carbonaceous claystone and dark gray to black fissile, carbonaceous shales. One thin bed of calcareous sandstone (possibly siderite) with plant-leaf fossils. Seatrock inaccessible. See app. C for description of coal-bearing section.
15	Capps Glacier area	CG4	50 ft	1	About 20 ft exposed	Slight	Good lateral exposure of Capps seam along headland tributary of Capps Creek. One prominent volcanic-ash parting and several other minor partings occur within the coal seam. Locally burned. See app. C for description of the coal-bearing section.
16	Capps Glacier area	CG5	130 ft	2, Capps and Waterfall beds	About 30 ft	Slight	Observed from across the valley on the south wall of Capps Creek canyon along inaccessible cliffs, full thickness of coal beds exposed.
17	Chuitna River	CR1	30 ft exposed	...	...	...	White-weathering pebbly sandstone beneath the Chuitna bed; coarse grained, locally slightly clayey; coal forms an anticlinal rim around top of outcrop.
18	Chuitna River	CR2	20 ft exposed	1	10 ft exposed	30°	Back of anticline, exposure of Chuitna coal bed.
19	Chuitna River	CR3	10 ft	1	About 6 ft exposed	30°	Exposure of Chuitna bed along stream drainage; one limb of anticline forms bottom of stream bed. See app. C for description of coal-bearing section.
20	Chuitna River	CR4	Usually <10 ft	1	Varies, generally 4-6 ft exposed	30°	Coal at this locale is in the northeast-trending anticline described at CR2 and CR3.
21	Chuitna River	CR5	20 ft	2	8 ft	4°	Two seams separated by a 1.5-ft parting of claystone. Coal extremely weathered at this exposure. See app. C for description of coal-bearing section.
22	Chuitna River	CR6	Up to 80 ft exposed, but largely inaccessible	1	>20 ft	Nearly horizontal	Outcrop of seatrock of Chuitna bed; weathered, friable sandstone and loose sand, relatively clean, fine to medium-grained, predominantly quartz, but with disseminated black organic matter and extremely fine muscovite flakes.
23	Chuitna River	CR7	...	...	...	...	Outcrop of baked sandstone and shale with imprints of leaf fossils. Burn material—scoria, porcellanite, clinker, 'red dog.' Different stages of oxidation and varieties of vesicular hematite; local admixtures of pyrolusite (MnO_2).
24	Chuitna River	CR8	60 ft	1	10 ft	5°	Distinctive differential weathering surfaces (anastamoses) on sandstone roof rock of Chuitna coal bed. The basal portion of the coal bed (1-2 ft) appears to be burned. Described from across river.
25	Chuitna River	CR9	80 ft	1	30 ft	<5°	Good exposure of Chuitna bed along southwest wall of promontory. Possible volcanic-ash parting within coal seam. See app. C for description of coal-bearing section
26	Chuitna River	CR10	90 ft	1	6 ft	15°	Exposure includes large area of scoria and baked shale above the coal bed on the south valley wall of the Chuitna River. Monocline on westward extension (possibly resulting from fault drag) flattens out to the east. Extensive burn talus slopes toward basal portion of outcrop. See app. C for description of coal-bearing section.
27	Coal Creek	CC1	200 ft	...	...	...	Thick section of Kenai Group strata exposed without coal beds, predominantly petromictic conglomerates and pebbly sandstones, but with thin carbonaceous shale and claystone interbeds. Section overlies coal-bearing strata downstream.

28	Coal Creek	CC2	10 ft exposed	1	2 ft	Nearly horizontal	Thin coal seam with roof and floor exposed. Described from across stream.
29	Coal Creek	CC3	40 ft exposed	1	About 25 ft	4°	Good exposure of coal seam and seatrock, but roof is covered. Outcrop largely inaccessible.
30	Drill Creek	DC	60 ft exposed	1	>50 ft	20°	Coal platy to slightly blocky, firm to hard with interbands of vitrain. Coal exposed in shallow synclinal basin on southern bank of Drill Creek. Barnes (1966) reported that this bed was exposed in a sampling trench excavated by the U.S. Bureau of Mines in 1960.
31	Fairview Mtn.	FM1	200 ft	6	4 ft	35°	Seams A-F. The two lowest coal beds (seams A and B) are poorly exposed and highly weathered. The coal beds could thicken considerably downdip. Overburden section consists predominantly of petromictic conglomerates with coal and graphite cobbles and gravels. See app. C for description of coal-bearing section.
32	Fairview Mtn.	FM2	50 ft	2	4 ft	25°	Represents two lowest beds exposed at FM1 (seams A and B). The coal beds were exposed only by extensive digging at an outcrop on the northwest slope of Fairview Mountain. See app. C for description of coal-bearing section
33	Friday Creek	FC	20 ft	1	12 ft exposed down to creek level	Nearly horizontal	Coal is hard, platy, ashy, locally vitrain-banded, but predominantly dull. Roof and floor unexposed.
34	Johnson Creek	JC1	>200 ft; only basal 20 ft described	. .	. . .	. . .	Lower section of exposure is composed of dark-gray graphitic claystone and graphite with white quartz veins, fracture fills, and nodules. A white calcite zone and an aquamarine weathering rim forms the boundary between the graphite and quartz.
35	Johnson Creek	JC2	150 ft	3, only lower bed accessible	<1 ft	25°	Coal appears thermally altered, vitreous, with conchoidal fracture. Carbonaceous shale forms roof and floor. See app. C for description of coal-bearing section.
36	Johnson Creek	JC3	50 ft exposed	1	6 ft	13°	Crops out in south wall of creek. Predominantly a dull, platy coal with few interbanded bright coal layers. Located at base of quartz-pebble conglomerate and pebbly sandstone sequence. Coal bed has thin carbonaceous claystone parting toward base. Ironstone nodules occur locally in the roof and floor materials. Some burn material in immediate area. See app. C for description of coal-bearing section.
37	Petersville area	PA1	172 ft	3	1 ft	Moderate	Outcrop located on west wall of Short Creek, a southward-flowing tributary of Cache Creek. Rapid vertical and lateral changes in lithologic facies. Coals are thin, hard, dull, and blocky. Overburden includes a claystone with distinctive coalified rootlets near the top of the stratigraphic sequence. See app. C for description of coal-bearing section.
38	Petersville area	PA2	Varies laterally	1	4 ft	Near vertical	Possible volcanic-ash parting in center of coal seam. Coal is woody. A dark-gray carbonaceous, feldspathic graywacke stands in relief about 15 ft above coal bed. Exposure on southwest wall of tributary of South Fork Creek on southeast flank of Peters Hills. See app. C for description of coal-bearing section.
39	Petersville area	PA3	50 ft	1	2 ft of coal separated by 0.5-ft parting	45°	Outcrop located on Peters Creek near Lampoon Pond. Pebbly, coarse-grained sandstone roof and floor exposed.
40	Saturday Creek	SC1	15 ft	. . .	. . .	. .	Banded claystone unit beneath coal exposed at SC2. Unit contains large oval concretions (up to 5 ft diam) with hard sandstone centers. Some concretions have abundant coal banding and carbonaceous root, branch, and leaf impressions; others have iron-rich (hematite) cores.
41	Saturday Creek	SC2	50 ft	1	8 ft	30°	Possible flow-roll (ball and pillow) structures exhibited in prominent ledge about 6 ft below bottom of coal seam. See app. C for description of coal-bearing section.
42	Saturday Creek	SC3	40 ft	1	10 ft	32°	Channel cutout (exposed in cross section) at west side of outcrop; channel filled with sandstone and conglomerate. See app. C for description of coal-bearing section.

Table A1. *Coal locales* (cont.)

Locale no.	Location	Code	Outcrop-section thickness	No. of coal beds	Maximum coal-bed thickness	Dip	General comments
43	Saturday Creek	SC4	90 ft	4	3 ft; top 2 beds separated by 2-ft parting	25°	Overburden largely covered but claystone roof of top seam exposed by trenching. One 0.3 ft stringer of extremely hard coal that has conchoidal fracture. See app. C for description of coal-bearing section.
44	Skwentna River	SR	60 ft exposed	2, only upper seam accessible	Upper seam 2 ft; lower seam approx. 5 ft exposed	6°	Second seam of coal crops out about 100 yd west at stream level. Claystone roof and carbonaceous shale floor exposed. Coal predominantly dull, platy, locally bony; quality deteriorates toward base of seam. See app. C for description of coal-bearing section.
45	Sunflower Creek	SuC	70 ft	1	> 50 ft	Top 25°, basal part of bed approx. 50°	Lower portion of bed slumped. Roof and seatrock of coal not exposed. Appears to be very localized, near Mesozoic rocks. See app. C for description of coal-bearing section.
46	Talachulitna River	TR	10 ft	1	3 ft	18°	Metamorphosed Jurassic-Cretaceous greenstone rocks faulted and juxtaposed against coal about 100 ft upstream. See app. C for description of coal-bearing section.
47	Wolverine Creek	WC1	Varies laterally	2	7 ft	Nearly vertical	Located at northern extremity of Mount Susitna. Two seams exposed, but section probably repeated. Claystone roof and floor well exposed.
48	Wolverine Creek	WC2	Varies laterally	2	2 ft	Steep	Claystone roof of upper seam contains distinctive iron-rich (hematite core; limonite rim) septarian nodules up to 2 in. diam. See app. C for description of coal-bearing section.

Table A2. *Sample inventory.*

Locale no.	Name	Site code	Samples: Coal	Samples: Overburden, interburden (partings), and seatrock	Samples: Petrographic	Comments
1	Beluga River	BR1	5	11	0	See app. C for sample locations.
2	Beshta Bay	BB1	BB1-1 (channel)	0	BB1-1p	Grab sample for petrography taken near center of outcropping seam.
3	Camp Creek	CpC1	CpC1-1 (channel)	0	CpC1-2 thru CpC1-7	Petrographic samples taken at intervals within seam.
4	Canyon Creek	CnC1	CnC1-1 (channel)	0	CnC1-2 thru CnC1-7	"
5	"	CnC2	CnC2-1 (channel)	0	CnC2-2 thru CnC2-6	"
6	"	CnC3	0	CnC3-1 thru CnC3-5	0	Samples of gradational zones of burn material.
7	"	CnC4	CnC4-1 (channel)	0	CnC4-2 thru CnC4-11	Petrographic samples taken at intervals within seam.
8	"	CnC5	0	4	0	See app. C for sample locations.
9	"	CnC6	CnC6-1 (channel)	0	CnC6-2 thru CnC6-6	Petrographic samples taken at intervals within seam.
10	"	CnC7	1 (channel)	0	9	See app. C for sample locations.
11	"	CnC8	1 (channel)	3	0	"
12	Capps Glacier area	CG1	CG1-1 (channel)	CG1-1 uncl	CG1-1p	Petrographic sample taken near middle of outcropping portion of seam.
13	"	CG2	0	0	0	No samples collected.
14	"	CG3	1 (channel)	9	3	See app. C for sample locations.
15	"	CG4	5 (channels of seam and portions of)	2	10	"
16	"	CG5	0	0	0	No samples collected.
17	Chuitna River	CR1	0	CR1-1	0	Sample of white-weathering pebbly sandstone.
18	"	CR2	0	0	0	No samples collected.
19	"	CR3	1 (channel)	2	1	See app. C for sample locations.
20	"	CR4	0	0	0	No samples collected.
21	"	CR5	2 (channels of portions of seam)	1	2	See app. C for sample locations.
22	"	CR6	CR6-1 (channel)	0	0	---
23	"	CR7	0	CR7-1	0	Baked sandstone.
24	"	CR8	0	0	0	No samples collected.
25	"	CR9	2 (channels of portions of seam)	2	7	See app. C for sample locations.
26	"	CR10	1 (channel)	1	5	See app. C for sample locations.

Table A2. *Sample inventory* (cont.)

Locale no.	Name	Site code	Samples: Coal	Samples: Overburden, interburden (partings), and seatrock	Samples: Petrographic	Comments
27	Coal Creek	CC1	0	0	0	No samples collected.
28	"	CC2	0	0	0	"
29	"	CC3	CC3-1 thru CC3-4 (channels of seam	CC3 uncl	CC3-1p thru CC3-4p	Petrographic samples taken near center of channeled sections of outcropping seam.
30	Drill Creek	DC1	DC1-1, DC1-2 (channels top and bottom half of outcropping seam)	0	DC1-1p DC1-2p	Petrographic samples collected near center of channeled sections.
31	Fairview Mountain	FM1	5	10	9	See app. C for sample locations.
32	"	FM2	3	4	4	"
33	Friday Creek	FrC1	FrC1-1 (channel)	0	0	---
34	Johnson Creek	JC1	0	JC1-1 JC1-2 JC1-3	0	---
35	"	JC2	1 (channel)	3	1	See app. C for sample locations.
36	"	JC3	2 (channels)	4	0	"
37	Petersville area	PA1	3 (channels)	35	2	"
38	"	PA2	1 (channel)	2	1	"
39	"	PA3	2 (channels)	1	2	"
40	Saturday Creek	SC1	0	SC1-1 SC1-2	0	---
41	"	SC2	2	1	2	See app. C for sample locations.
42	"	SC3	1	3	1	"
43	"	SC4	4	9	6	"
44	Skwentna River	SR1	1	3	2	"
45	Sunflower Creek	SuC1	0	0	0	No samples collected.
46	Talachulitna River	TR1	1	2	1	See app. C for sample locations.
47	Wolverine Creek	WC1	2	4	2	"
48	"	WC2	4	11	3	"

Table A-3. *Specific location information for Susitna lowland coal and overburden sampling sites.*

Site code	Coal-resource region	Quadrangle	Township	Range	Section	Latitude	Longitude
BR1	Southcentral	Tyonek A-4	13 N.	11 W.	14	61°12'46"	151°11'3"
BB1	Southcentral	Tyonek A-4	11 N.	11 W.	19	61°1'54"	151°18'27"
CpC1	Southcentral	Talkeetna B-3	27 N.	12 W.	27	62°23'43"	151°28'46"
CnC1	Southcentral	Tyonek D-5	19 N.	13 W.	6	61°45'56"	151°41'13"
CnC2	Southcentral	Tyonek D-5	19 N.	13 W.	7	61°45'27"	151°42'14"
CnC3	Southcentral	Tyonek D-5	19 N.	13 W.	7	61°45'24"	151°42'14"
CnC4	Southcentral	Tyonek D-5	19 N.	13 W.	7	61°45'21"	151°42'9"
CnC5	Southcentral	Tyonek D-5	19 N.	13 W.	6	61°45'52"	151°41'13"
CnC6	Southcentral	Tyonek D-5	20 N.	14 W.	35	61°46'42"	151°45'26"
CnC7	Southcentral	Tyonek D-5	20 N.	13 W.	19	61°48'10"	151°42'36"
CnC8	Southcentral	Tyonek D-5	20 N.	13 W.	19	61°48'5"	151°41'36"
CG1	Southcentral	Tyonek B-5	14 N.	14 W.	15	61°18'7"	151°45'30"
CG2	Southcentral	Tyonek B-5	14 N.	14 W.	23	61°17'21"	151°43'18"
CG3	Southcentral	Tyonek B-5	14 N.	14 W.	13	61°17'57"	151°43'3"
CG4	Southcentral	Tyonek B-5	14 N.	14 W.	27	61°16'50"	151°46'15"
CG5	Southcentral	Tyonek B-5	14 N.	14 W.	24	61°17'13"	151°42'42"
CR1	Southcentral	Tyonek A-5	13 N.	13 W.	29	61°11'1"	151°38'00"
CR2	Southcentral	Tyonek A-5	13 N.	13 W.	29	61°10'58"	151°37'54"
CR3	Southcentral	Tyonek A-5	13 N.	13 W.	28	61°11'4"	151°37'38"
CR4	Southcentral	Tyonek A-5	13 N.	13 W.	28	61°11'13"	151°37'37"
CR5	Southcentral	Tyonek A-4	12 N.	12 W.	24	61°7'13"	151°18'56"
CR6	Southcentral	Tyonek A-4	12 N.	12 W.	6	61°9'16"	151°29'14"
CR7	Southcentral	Tyonek A-5	13 N.	13 W.	35	61°10'3"	151°32'30"
CR8	Southcentral	Tyonek A-5	12 N.	13 W.	1	61°9'11"	151°30'8"
CR9	Southcentral	Tyonek A-5	12 N.	13 W	1	61°9'23"	151°30'31"
CR10	Southcentral	Tyonek A-5	13 N.	13 W.	27	61°11'18"	151°35'32"
CC1	Southcentral	Tyonek B-5	16 N.	13 W.	26	61°26'48"	151°32'52"
CC2	Southcentral	Tyonek B-5	16 N.	13 W.	36	61°26'13"	151°31'30"
CC3	Southcentral	Tyonek B-5	16 N.	13 W.	36	61°26'10"	151°30'38"
DC1	Southcentral	Tyonek B-4	15 N.	12 W.	11	61°24'16"	151°22'50"
FM1	Southcentral	Talkeetna B-4	26 N.	12 W.	7	62°21'52"	151°34'40"
FM2	Southcentral	Talkeetna B-4	26 N.	12 W.	6	62°22'4"	151°33'56"
FC1	Southcentral	Tyonek C-5	19 N.	13 W.	35	61°41'36"	151°35'12"
JC1	Southcentral	Talkeetna A-5	23 N.	15 W.	21	62°3'58"	152°2'00"
JC2	Southcentral	Talkeetna A-4	23 N.	15 W.	23	62°3'49"	151°57'47"
JC3	Southcentral	Talkeetna A-4	23 N.	14 W.	30	62°3'21"	151°54'18"
PA1	Southcentral	Talkeetna B-3	28 N.	10 W.	36	62°28'28"	151°2'6"
PA2	Southcentral	Talkeetna B-2	27 N.	8 W.	18	62°25"46"	150°49'33"
PA3	Southcentral	Talkeetna B-2	27 N.	8 W.	22	62°25'00"	150°44'21"
SC1	Southcentral	Tyonek C-5	18 N.	13 W.	1	61°40'24"	151°33'31"
SC2	Southcentral	Tyonek C-5	18 N.	13 W.	2	61°40'42"	151°34'12"
SC3	Southcentral	Tyonek C-5	18 N.	13 W.	2	61°40'47"	151°34'36"
SC4	Southcentral	Tyonek C-5	18 N.	13 W.	2	61°40'53"	151°35'3"
SR1	Southcentral	Tyonek D-6	22 N.	15 W.	23	61°58'42"	151°57'27"
SuC1	Southcentral	Talkeetna B-3	27 N.	12 W.	26	62°24'17"	151°27'3"
TR1	Southcentral	Tyonek C-4	19 N.	12 W.	21	61°43'6"	151°27'9"
WC1	Southcentral	Tyonek C-3	17 N.	9 W.	1	61°35'12"	150°49'41"
WC2	Southcentral	Tyonek C-3	17 N.	9 W.	24	61°33'15"	150°50'4"

APPENDIX B
Coal-analysis data

Table B-1. *Concentration of major oxides in ash of raw coals (%). From Rao and Wolff, 1981.*

Coal field, bed	ASTM rank	Thickness, m (ft)	Sample	Ash (%)								
				SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
Beluga, Waterfall	Subbit. C	9.1 (30)	UA-113	41.0	28.9	6.7	1.9	16.6	0.18	2.1	0.8	0.10
Yentna, Sunflower (upper)	Lignite	3.0 (10)	UA-115	16.8	33.3	9.5	6.3	28.0	0.26	1.0	1.1	0.12
Yentna, Sunflower (lower)	Lignite	3.0 (10)	UA-116	11.6	27.9	10.6	7.4	37.2	0.27	0.6	0.8	0.13

Table B-2. *Concentration of trace elements in raw coal ashes (ppm). From Rao and Wolff, 1981.*

Sample	Ag	B	Ba	Co	Cu[a]	Cr	Ga	Mo	Ni[a]	Pb	Sn	V	Zn[a]	Zr
UA-113	N.D.	130	5,200	88	164	230	52	N.D.	121	110	N.D.	360	182	420
UA-115	1.3	320	5,700	35	230	160	47	N.D.	130	42	48	220	100	480
UA-116	1.6	370	5,500	98	250	170	31	10	165	83	28	240	120	750

[a]Atomic absorption.

Table B-3. *Vitrinite-reflectance data as measured from ulminite macerals, selected Susitna lowland coals.*

Sample	Frequency histogram-vitrinite types (%) V2	V3	V4	V5	V6	Mean maximum reflectance ($\bar{R}om$%)
BB1-1		26	42	32		0.45
BR1-1	20	70	4	4	2	0.34
BR1-4	48	42	10			0.31
BR1-8		62	38			0.38
BR1-12	46	42	12			0.32
BR1-15		74	22	4		0.38
CpC1-1	12	68	20			0.35
CnC1-1	2	54	42	2		0.39
CnC2-1	18	70	12			0.33
CnC2-2	16	76	8			0.33
CnC2-3		98	2			0.34
CnC2-4	6	92	2			0.34
CnC2-5	8	92				0.32
CnC2-6	2	94	4			0.35
CnC4-1	44	54	2			0.30
CnC4-2	34	56	10			0.32
CnC4-3	32	62	6			0.31
CnC4-4	26	70	4			0.31
CnC4-5	4	94	2			0.35
CnC4-6	56	42	2			0.30
CnC4-7	82	16	2			0.37
CnC4-8	26	74				0.32
CnC4-9	6	72	22			0.37
CnC4-10	12	88				0.33
CnC4-11	8	88	4			0.34
CnC6-1	12	80	8			0.34
CnC7-1	34	62	2	2		0.31
CnC8-2	4	88	8			0.34
CG1-1		42	52	6		0.41
CG3-10		82	16	2		0.36
CG4-1		32	52	14		0.42
CG4-2	8	70	22			0.36
CG4-4	14	48	36	2		0.37
CG4-5	18	68	12	2		0.35
CR3-1		76	22	2		0.37
CR5-1		58	38	4		0.39
CR5-3	14	82	4			0.34
CR6-1		42	44	12	2	0.42
CR9-1		60	38	2		0.38
CR10-1		64	34	2		0.39
CC3-1	24	58	16	2		0.34
CC3-4		72	28			0.37
DC1-1	6	48	26	18	2	0.41
DC1-2	4	88	8			0.35
FM1-2		68	26	6		0.38
FM1-4		48	48	4		0.40
FM1-7	8	56	34	2		0.37
FM1-10	10	70	18	2		0.36
FM1-13		50	50			0.39
FM2-1	58	36	6			0.30
FM2-2	12	78	10			0.34
FM2-6	30	54	16			0.33
FM2-8	100					0.23
FrC1-1	4	64	28		4	0.38
JC3-1	2	76	20	2		0.37
JC3-5	12	66	18	4		0.37

Table B-3. *Vitrinite-reflectance data, selected Susitna lowland coals* (cont.)

Sample	Frequency histogram-vitrinite types (%) V2	V3	V4	V5	V6	Mean maximum reflectance ($\bar{R}om\%$)
PA1-5	24	68	8			0.33
PA1-32		86	14			0.36
PA1-34	42	58				0.31
PA2-1	22	64	14			0.34
PA3-1		54	44	2		0.40
SC2-3	2	62	36			0.38
SC3-1		72	22	6		0.38
SC4-2	40	46	14			0.33
SC4-4		74	24	2		0.38
SC4-7	56	32	12			0.30
SC4-12	32	62	6			0.33
SR1-2	12	68	20			0.35
TR1-1		30	46	24		0.44
WC1-3	6	78	14	2		0.35
WC1-4		66	30	4		0.38
WC2-4		18	64	18		0.45
WC2-9		56	38	6		0.38
WC2-10		36	54	10		0.42
WC2-14		64	34	2		0.38

Table B-4. *Relationship between rank and vitrinite reflectance. Modified from Rao, 1976 and Ting, 1978. By this classification, all Susitna lowland coals are subbituminous.*

Rank	Reflectance ($\bar{R}om$, %)
Lignite	0.20-0.30
Subbituminous coal	0.30-0.50
High-volatile bituminous coal	0.50-1.0
Medium-volatile bituminous coal	1.0-1.5
Low-volatile bituminous coal	1.5-2.0
Semianthracite	2.0-2.5
Anthracite	2.5-5.0
Meta-anthracite	>5.0

Table B-5. *Calculations relating to coal quality.*

Sample	Carbon ratio[a]	Perch & Russell ratio[b]	Fuel ratio[c]	H value of Lord[d] (Btu/lb)	Dry, mm-free FC (%)[e]	Dry, mm-free VM (%)[f]	Moist, mm-free Btu (per lb)[g]	Apparent rank	Mineral matter (%)[h]	DuLong's equation[i] (Btu/lb)
BB1-1	50.4	0.82	1.02	11,510	50.9	49.1	9,880	Subbit B	9.1	
BR1-1	40.6	0.85	0.68	10,627	41.1	58.9	9,650	Subbit B	12.2	9,010
BR1-4	41.0	0.82	0.69	10,476	41.3	58.7	9,270	Subbit C	8.1	
BR1-8	41.9	0.82	0.72	10,501	42.5	57.5	9,400	Subbit C	11.7	
BR1-12	40.4	0.81	0.68	10,143	41.0	59.0	9,240	Subbit C	12.8	
BR1-15	41.7	0.82	0.72	10,069	42.2	57.8	9,200	Subbit C	11.4	
CpC1-1	43.2	0.83	0.76	11,384	46.6	53.4	9,820	Subbit B	2.6	
CnC1-1	49.6	0.87	0.98	11,336	50.0	50.0	10,480	Subbit B	9.5	
CnC2-1	48.7	0.84	0.95	10,827	49.4	50.6	9,570	Subbit B	14.0	
CnC4-1	49.2	0.85	0.97	11,621	49.6	50.4	10,270	Subbit B	8.9	
CnC6-1	45.8	0.81	0.85	11,135	46.2	53.8	10,070	Subbit B	8.4	
CnC7-1	49.2	0.86	0.97	9,833	49.6	50.4	9,930	Subbit B	7.2	9,800
CnC8-2	49.2	0.86	0.97	10,800	49.7	50.3	10,180	Subbit B	9.4	9,820
CC3-1	48.7	0.77	0.95	10,583	49.0	51.0	9,050	Subbit C	6.4	
CC3-2	46.6	0.82	0.87	10,342	47.5	52.5	9,750	Subbit B	16.5	
CC3-3	47.4	0.78	0.90	7,620	48.0	52.0	9,490	Subbit C	10.0	
CC3-4	44.9	0.78	0.81	9,782	45.4	54.6	9,240	Subbit C	10.9	
CG1-1	47.4	0.76	0.90	10,265	47.8	52.2	9,050	Subbit C	8.0	
CG3-10	39.7	0.76	0.66	8,072	41.8	58.2	8,490	Subbit C	33.8	6,650
CG4-1	48.8	0.82	0.95	9,971	50.3	49.7	9,430	Subbit C	24.1	8,020
CG4-2	46.6	- - -	0.87	- - -	- - -	- - -	- - -	- - -	- - -	
CG4-3	46.0	0.80	0.85	10,203	46.6	53.4	9,490	Subbit C	9.8	
CG4-4	50.2	0.81[j]	1.01	11,482	51.4[j]	48.6[j]	9,380	Subbit C[j]	19.4	
CG4-5	47.0	0.81[j]	0.89	11,599	48.1[j]	51.9[j]	9,500	Subbit B[j]	20.1	
CR3-1	52.6	0.83	1.11	11,435	53.6	46.4	9,990	Subbit B	17.8	
CR5-1	45.3	0.82	0.83	9,223	45.9	54.1	9,370	Subbit C	11.7	
CR5-3	44.6	0.83	0.80	9,879	44.9	55.1	9,660	Subbit B	7.1	
CR6-1	46.1	0.85	0.86	9,606	46.6	53.4	9,190	Subbit C	10.9	
CR9-1	46.5	0.84	0.87	10,635	47.0	53.0	9,760	Subbit B	9.9	
CR9-3	46.0	0.85	0.85	10,375	46.5	53.5	9,940	Subbit B	11.4	9,280
CR10-1	47.3	0.84	0.90	11,447	48.4	51.6	10,160	Subbit B	20.9	8,810
DC1-1	51.3	0.84	1.05	11,415	51.8	48.2	10,030	Subbit B	10.0	
DC1-2	48.2	0.83	0.93	11,282	49.2	50.8	9,930	Subbit B	18.0	
FM1-2	47.5	0.85	0.90	9,736	50.4	49.6	9,580	Subbit B	39.6	
FM1-4	47.1	0.84	0.89	9,986	48.8	51.2	9,620	Subbit B	28.5	
FM1-7	50.5	0.85	0.99	10,447	50.6	49.4	9,870	Subbit B	16.1	8,950
FM1-10	46.7	0.84	0.88	10,240	48.4	51.6	9,590	Subbit B	26.1	
FM1-13	44.9	0.81	0.81	11,087	45.9	54.1	10,830	Subbit A	20.2	
FM2-1	42.2	0.80	0.73	10,450	42.7	57.3	8,870	Subbit C	12.5	
FM2-2	43.3	0.85	0.76	10,663	43.7	56.3	9,850	Subbit B	10.0	
FM2-6	36.8	0.93	0.58	9,022	41.0	59.0	10,350	Subbit B	56.0	
FrC1-1	47.0	0.84	1.13	10,529	48.2	51.8	9,900	Subbit B	21.5	
JC2-2	54.5	0.85	1.20	8,995	54.9	45.1	10,240	Subbit B	6.3	
JC3-1	42.1	0.84	0.73	9,841	42.9	57.1	8,770	Subbit C	16.7	8,270
JC3-5	45.3	0.85	0.83	8,361	46.3	53.7	9,630	Subbit B	18.9	
PA1-5	45.4	0.83	0.83	8,909	46.2	53.8	9,540	Subbit B	14.7	
PA1-32	40.1	0.82	0.67	10,509	40.6	59.4	10,260	Subbit B	12.0	
PA1-34	36.8	0.92	0.58	10,288	38.4	61.6	11,100	Subbit A	33.9	

PA2-1	39.6	0.75	0.66	9,744	40.6	59.4	8,660	Subbit C	22.2	
PA3-1	41.2	0.85	0.70	8,170	42.9	57.1	9,430	Subbit C	29.8	
PA3-3	43.5	0.82	1.30	7,927	44.8	55.2	9,270	Subbit C	23.0	
SC2-2	46.5	0.83	0.87	9,872	46.9	53.1	9,210	Subbit C	7.7	
SC2-3	49.7	0.84	0.99	10,727	50.0	50.0	9,670	Subbit B	6.7	
SC3-1	47.9	0.80	0.92	10,638	49.1	50.9	9,600	Subbit B	21.2	8,120
SC4-2	46.2	0.83	0.86	9,738	46.6	53.4	9,190	Subbit C	9.1	
SC4-4	47.1	0.84	0.89	10,553	47.5	52.5	9,700	Subbit B	7.2	
SC4-7	50.9	0.82	1.04	10,451	51.1	48.9	9,790	Subbit B	3.2	
SC4-12	46.5	0.80	0.87	10,553	47.8	52.2	9,620	Subbit B	22.2	
SR1-2	50.5	0.83	1.02	8,186	51.9	48.1	9,560	Subbit B	24.4	
TR1-1	51.1	0.81	1.04	12,521	51.4	48.6	11,500	Subbit A	4.8	
WC1-3	54.1	0.84	1.18	9,277	54.7	45.3	10,230	Subbit B	8.8	
WC1-4	44.0	0.82	0.78	9,013	46.0	54.0	9,660	Subbit B	32.2	
WC2-4	47.9	0.82	0.92	9,232	49.5	50.5	9,840	Subbit B	25.3	
WC2-9	49.7	0.84	0.99	13,688	51.7	48.3	13,090	Hv B bit	29.5	
WC2-10	49.7	0.83	0.99	11,118	50.9	49.1	10,090	Subbit B	20.5	
WC2-14	49.6	0.82	0.98	10,004	51.3	48.7	9,710	Subbit B	26.4	

[a] $\frac{FC}{FC + VM} \times 100$

[b] $R = \frac{\text{Moist, mm-free Btu}}{\text{Dry, mm-free Btu}}$

[c] $\frac{FC}{VM}$

[d] $R = \frac{Btu - 4050S}{100 - (M+A+S)} \times 100$

[e] $\frac{FC - 0.15S}{100 - (M+1.08A+0.55S)} \times 100$

[f] 100 - dry, mm-free FC

[g] $\frac{Btu - 50S}{100 - (1.08A + 0.55S)} \times 100$

[h] $MM = \frac{1.08A + 0.55S}{[100-(1.08A + 0.55S)]/1.35 + (1.08A + 0.55S)/2.8}$

[i] $Q = \frac{1}{100} [14{,}544 \times \%C + 62{,}028 (\%H - \%O/8) + 4050 \times \%S]$

[j] The total sulfur value used in calculations was 0.01 when actual value by analysis was <0.01.

Table B-6. *Classification of coals by rank.*[a] *From ASTM, 1981.*[b]

Class	Group	Fixed carbon limits, percent (dry, mineral-matter-free basis)		Volatile matter limits, percent (dry, mineral-matter-free basis)		Calorific value limits, Btu per pound (moist,[c], mineral-matter-free basis)		Agglomerating character
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than	
I. Anthracitic	1. Meta-anthracite	98	---	---	2	---	---	Nonagglomerating
	2. Anthracite	92	98	2	8	---	---	
	3. Semianthracite[d]	86	92	8	14	---	---	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	---	---	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	---	---	
	3. High volatile A bituminous coal	---	69	31	---	14 000[f]	---	
	4. High volatile B bituminous coal	---	---	---	---	13 000[f]	14 000	
	5. High volatile C bituminous coal	---	---	---	---	11 500	13 000	
						10 500	11 500	Agglomerating
III. Subbituminous	1. Subbituminous A coal	---	---	---	---	10 500	11 500	Nonagglomerating
	2. Subbituminous B coal	---	---	---	---	9 500	10 500	
	3. Subbituminous C coal	---	---	---	---	8 300	9 500	
IV. Lignitic	1. Lignite A	---	---	---	---	6 300	8 300	
	2. Lignite B	---	---	---	---	---	6 300	

[a]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[b]American Society for Testing and Materials, 1981, Standard specifications for classification of coals by rank (ASTM designation D-388-77): 1981 Annual book of ASTM standards, part 26, p. 212-216.

[c]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[d]If agglomerating, classify in low-volatile group of the bituminous class.

[e]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in high volatile C bituminous group.

[f]Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

Table B-7. *Total sulfur, selected Susitna lowland coal samples.*

Sample	Total sulfur (%)		
	1[a]	2	3
BR1-4	0.16	0.19	0.21
BR1-8	0.19	0.23	0.26
BR1-12	0.22	0.26	0.30
BR1-15	0.21	0.25	0.28
BR1-1	0.10	0.12	0.14
CpC1-1	0.08	0.09	0.09
CnC1-1	0.14	0.16	0.18
CnC2-1	0.11	0.13	0.15
CnC4-1	0.09	0.10	0.11
CnC6-1	0.11	0.13	0.15
CG1-1	0.23	0.29	0.32
CG3-10	0.40	0.48	0.66
CG4-3	0.31	0.38	0.43
CG4-4	<0.01	<0.01	<0.01
CG4-5	<0.01	<0.01	<0.01
CR3-1	0.11	0.13	0.16
CR5-1	0.41	0.49	0.57
CR5-3	0.34	0.40	0.44
CR6-1	0.23	0.27	0.30
CR9-1	0.19	0.23	0.26
CC3-1	0.21	0.27	0.29
CC3-2	0.27	0.32	0.39
CC3-3	0.73	0.91	1.03
CC3-4	0.35	0.44	0.50
DC1-1	0.09	0.11	0.12
DC1-2	0.11	0.13	0.16
FM1-2	0.19	0.21	0.36
FM1-4	0.23	0.27	0.39
FM1-10	0.18	0.20	0.28
FM1-13	0.22	0.24	0.31
FM2-1	0.11	0.13	0.16
FM2-2	0.17	0.19	0.22
FM2-6	0.22	0.23	0.53
FrC1-1	0.20	0.23	0.30
JC2-2	0.61	0.71	0.76
JC3-5	0.52	0.61	0.76
PA1-5	0.47	0.56	0.66
PA1-32	0.36	0.44	0.50
PA1-34	0.28	0.30	0.46
PA2-1	0.30	0.35	0.47
PA3-1	0.44	0.50	0.73
PA3-3	0.54	0.64	0.85
SC2-2	0.23	0.27	0.29
SC2-3	0.16	0.19	0.20
SC4-2	0.26	0.31	0.35
SC4-4	0.20	0.23	0.25
SC4-7	0.31	0.38	0.39
SC4-12	0.24	0.29	0.39
SR1-2	0.53	0.63	0.85
TR1-1	0.32	0.40	0.42
WC1-3	0.56	0.66	0.73
WC1-4	0.38	0.44	0.67
WC2-4	0.43	0.51	0.70
WC2-9	0.28	0.33	0.48
WC2-10	0.17	0.19	0.25
WC2-14	0.25	0.30	0.42

[a]1 - As received
2 - Moisture free
3 - Moisture and ash free

Table B-8. *Sulfur species, selected Susitna lowland coals (%).*

Sample	Organic			Pyritic			Sulfate			Total		
	1[a]	2	3	1	2	3	1	2	3	1	2	3
BR1-1	0.12	0.14	0.16	0.01	0.01	0.01	0.01	0.01	0.01	0.14	0.16	0.18
CnC7-1	0.31	0.37	0.39	0.01	0.01	0.01	0.03	0.03	0.04	0.35	0.41	0.44
CnC8-2	0.20	0.23	0.25	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.21	0.24	0.26
CG3-10	0.15	0.20	0.31	0.01	0.01	0.02	0.03	0.03	0.05	0.19	0.24	0.38
CG4-1	0.20	0.23	0.31	0.01	0.01	0.02	0.03	0.04	0.05	0.24	0.28	0.38
CR9-1	0.18	0.22	0.25	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.19	0.23	0.26
CR9-3	0.23	0.27	0.30	<0.01	<0.01	<0.01	0.02	0.02	0.03	0.25	0.29	0.33
CR10-1	0.10	0.11	0.15	<0.01	<0.01	<0.01	0.00	0.00	0.00	0.10	0.11	0.15
FM1-2	0.13	0.14	0.25	0.01	0.01	0.02	0.05	0.06	0.09	0.19	0.21	0.36
FM1-4	0.20	0.24	0.34	0.01	0.01	0.02	0.02	0.02	0.03	0.23	0.27	0.39
FM1-7	0.14	0.16	0.19	0.02	0.02	0.03	0.04	0.05	0.05	0.20	0.23	0.27
FM1-10	0.17	0.19	0.26	0.01	0.01	0.02	<0.01	<0.01	<0.01	0.18	0.20	0.28
FM1-13	0.21	0.23	0.30	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.22	0.24	0.31
FM2-2	0.15	0.17	0.20	0.01	0.01	0.01	0.01	0.01	0.01	0.17	0.19	0.22
FM2-6	0.21	0.22	0.51	0.01	0.01	0.02	<0.01	<0.01	<0.01	0.22	0.23	0.53
JC3-1	0.18	0.22	0.26	0.02	0.02	0.03	0.05	0.06	0.07	0.25	0.30	0.36
SC2-2	0.18	0.21	0.22	0.02	0.02	0.03	0.03	0.04	0.04	0.23	0.27	0.29
SC2-3	0.11	0.13	0.14	0.01	0.01	0.01	0.04	0.05	0.05	0.16	0.19	0.20
SC3-1	0.18	0.22	0.29	0.01	0.01	0.02	0.03	0.04	0.05	0.22	0.27	0.36
SC4-2	0.24	0.29	0.33	0.01	0.01	0.01	0.01	0.01	0.01	0.26	0.31	0.35
SC4-4	0.18	0.21	0.23	0.01	0.01	0.01	0.01	0.01	0.01	0.20	0.23	0.25
SR1-2	0.40	0.48	0.64	0.01	0.01	0.02	0.12	0.14	0.19	0.53	0.63	0.85
TR1-1	0.31	0.39	0.41	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.32	0.40	0.42
WC1-3	0.19	0.22	0.24	0.04	0.05	0.05	0.33	0.39	0.44	0.56	0.66	0.73
WC2-10	0.15	0.17	0.23	0.01	0.01	0.01	0.01	0.01	0.01	0.17	0.19	0.25

[a]1 - As received; 2 - moisture free; 3 - moisture and ash free.

Table B-9. *Ash (%) and chemical analyses on coal from the Beluga field, as-received basis (ppm). From Conwell, 1977b.*

Field sample	Ash (%)[a]	As[b]	F[c]	Hg[d]	Sb[e]	Se[f]	Th[g]	U[g]
1	22.6	6.0	145	0.07	1.9	0.2	5.9	1.79
2	17.9	7.5	90	0.04	1.2	0.2	<3.0	1.35
3	9.6	6.0	50	0.04	1.0	<0.1	<3.0	0.71
4	10.1	6.0	30	0.04	0.5	0.1	<3.0	0.65
5	13.9	4.0	110	0.05	1.6	0.4	5.3	1.50
6	7.3	2.0	20	0.02	0.6	<0.1	<3.0	0.76
7	5.0	2.0	25	0.03	0.4	<0.1	<3.0	<0.20

[a]Determined gravimetrically (ashed at 525°C).
[b]Determined by graphite furnace - atomic absorption method.
[c]Determined by specific-ion-electrode method.
[d]Determined by wet oxidation + atomic absorption method.
[e]Determined by Rhodamine-B method.
[f]Determined by X-ray fluorescence.
[g]Determined by delayed-neutron method.

Table B-10. *Chemical analyses on coal ash, major oxides, and chlorine (%) of coal from the Beluga field. From Conwell, 1977b.*

Field sample	Al_2O_3	SiO_2	CaO	P_2O_5	TiO_2	MnO	Fe_2O_3	K_2O	MgO	Na_2O[a]	SO_3	Cl
1	27	51	3.0	<1.0	0.87	0.05	3.8	2.40	1.18	0.17	2.6	0.20
2	28	47	5.6	<1.0	0.85	0.05	3.4	2.20	1.36	0.19	3.1	0.20
3	25	33	13.0	1.2	0.84	0.05	4.3	1.20	1.46	0.19	7.6	0.20
4	30	32	11.0	<1.0	1.40	0.05	4.2	0.32	0.91	0.10	7.8	0.20
5	23	44	6.3	1.4	1.20	0.05	3.6	1.90	3.20	0.23	3.0	0.20
6	19	22	13.0	1.3	0.91	0.05	5.6	0.91	4.95	0.17	18.0	0.20
7	21	21	17.0	<1.0	0.84	0.05	3.0	0.83	5.53	0.18	15.0	0.20

[a]Determined by atomic absorption; all others determined by X-ray fluorescence.

Table B-11. *Proximate analyses, ultimate analyses, and calorific value of coal from the Beluga field. From Conwell, 1977b.*

Field sample	Condition[a]	Proximate analyses (%) Moisture	Volatile matter	Fixed carbon	Ash	Ultimate analyses (%) Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Calorific value (Btu)
1–4 combined	1	7.0	41.1	36.0	15.9	5.2	53.3	0.7	24.7	0.2	9,160
	2	19.9	35.4	31.0	13.7	6.0	46.0	0.6	33.6	0.1	7,900
	3	---	44.2	38.7	17.1	4.8	57.4	0.7	19.8	0.2	9,860
	4	---	53.3	46.7	---	5.8	69.2	0.9	23.9	0.2	11,890
5–7 combined	1	7.6	43.0	41.2	8.2	5.4	58.2	1.1	26.9	0.2	9,910
	2	21.1	36.7	35.2	7.0	6.3	49.7	0.9	36.0	0.1	8,460
	3	---	46.5	44.6	8.9	4.9	63.0	1.1	21.9	0.2	10,730
	4	---	51.1	48.9	---	5.4	69.2	1.3	23.9	0.2	11,780

[a]1 - air dried; 2 - as received; 3 - moisture free; 4 - moisture and ash free.

Table B-12. *Chemical analyses on coal-ash trace elements (ppm) in coal from the Beluga field. From Conwell, 1977b.*

Field sample	B	Ba	Be	Cd[a]	Co	Cr	Cu[a]	Ga	La	Li[a]	Mn[a]	Mo	Nb	Ni	Pb[a]	Sc	Sr	V	Y	Yb	Zn[a]	Zr
1	70	3,000	7	<1	30	300	131	70	100	89	465	150	20	70	60	50	1,500	700	100	10	139	150
2	100	5,000	10	<1	50	300	115	70	<100	85	345	30	20	70	50	30	700	500	70	10	140	200
3	70	5,000	7	<1	50	150	108	70	100	49	430	15	20	100	30	30	1,500	300	100	15	163	150
4	50	5,000	10	<1	50	100	104	70	100	54	485	30	30	100	40	50	1,000	300	150	15	148	300
5	150	10,000	10	<1	50	300	239	70	100	54	310	30	30	100	40	50	1,000	700	100	15	90	150
6	150	10,000	3	<1	30	200	178	50	<100	32	325	20	20	70	25	30	1,000	500	70	7	80	150
7	300	10,000	3	<1	70	150	131	30	N	27	225	30	20	100	25	30	1,500	500	70	10	70	150

[a]Determined by atomic absorption; all others determined by six-step spectrographic analysis.
N - Not determined or below detection.
Elements not detected or below limit of determination include: Ag, Au, Bi, Cd, Pd, Pt, Sb, Te, W, Ce, Ge, Hf, In, Li, Re, Ta, Th, Tl, Eu, Pr, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, and Lu.

Table B-13. *Fusibility of ash and sulfur forms in coal from the Beluga field. From Conwell, 1977b.*

Field sample	Condition[a]	Fusibility (°F)			Sulfur form (%)		
		Initial deformation	Softening	Fluid	Sulfate	Pyritic	Organic
1, 2, 3, 4 combined	1	2,350	2,420	2,520	0.02	0.01	0.10
	2				0.02	0.01	0.13
	3				0.03	0.01	0.16
5, 6, 7 combined	1	2,200	2,230	2,260	0.03	0.00	0.10
	2				0.03	0.00	0.13
	3				0.04	0.00	0.14

[a]1 - air dried, 2 - as received, 3 - moisture free.

Table B-14. *Proximate analysis.*

Sample	Moisture (%)			Volatile matter (%)			Fixed carbon (%)			Ash (%)			Heating value (Btu/lb)		
	1[a]	2	3	1	2	3	1	2	3	1	2	3	1	2	3
BR1-1	14.2	--	--	44.3	51.6	59.4	30.3	35.3	40.6	11.2	13.1	--	8480	9880	11370
BR1-4	17.2	--	--	44.5	53.7	59.0	30.9	37.3	41.0	7.4	9.0	--	8530	10300	11310
BR1-8	17.3	--	--	41.8	50.5	58.0	30.2	36.6	42.0	10.7	12.9	--	8310	10060	11540
BR1-12	17.3	--	--	42.3	51.1	59.5	28.7	35.8	40.5	11.7	14.1	--	8070	9750	11360
BR1-15	16.7	--	--	42.5	51.1	58.4	30.4	36.4	41.6	10.4	12.5	--	8170	9810	11220
BB1-1	17.0	--	--	37.0	44.6	49.7	37.6	45.2	50.3	8.4	10.2	--	8980	10820	12050
CpC1-1	16.3	--	--	46.1	55.1	56.7	35.2	42.1	43.3	2.4	2.8	--	9570	11430	11770
CnC1-1	12.4	--	--	40.3	46.0	50.4	39.7	45.3	49.6	7.6	8.7	--	9620	10980	12020
CnC2-1	15.0	--	--	37.0	43.5	51.4	35.1	41.3	48.6	12.9	15.2	--	8240	9700	11440
CnC4-1	14.3	--	--	39.4	46.0	50.8	38.1	44.5	49.2	8.2	9.5	--	9360	10920	12070
CnC6-1	13.3	--	--	42.8	49.3	54.1	36.2	41.9	45.9	7.7	8.8	--	9820	11330	12430
CnC7-1	13.7	--	--	40.5	46.9	50.8	39.3	45.5	49.2	6.5	7.6	--	9230	10700	11570
CnC8-2	13.6	--	--	39.5	45.8	50.9	38.3	44.2	49.1	8.6	10.0	--	9230	10690	11870
CG1-1	20.3	--	--	38.1	47.8	52.6	34.3	43.0	47.4	7.3	9.2	--	8640	10840	11940
CG3-10	18.5	--	--	30.4	37.3	60.3	20.0	24.5	39.7	31.1	38.2	--	5640	6920	11190
CG4-1	15.4	--	--	31.9	37.7	51.2	30.4	35.9	48.8	22.3	26.4	--	7160	8460	11490
CG4-2	15.1	--	--	32.6	38.4	53.5	28.4	33.5	46.5	23.9	28.1	--	7060	8320	11580
CG4-3	19.0	--	--	38.9	48.0	54.0	33.2	41.0	46.0	8.9	11.0	--	8580	10600	11910
CG4-4	16.5	--	--	32.6	39.1	49.8	32.9	39.3	50.2	18.0	21.6	--	7560	9050	11540
CG4-5	16.3	--	--	34.5	41.2	53.0	30.6	36.6	47.0	18.6	22.2	--	7590	9070	11660
CR3-1	15.5	--	--	32.3	38.2	47.4	35.8	42.3	52.6	16.4	19.5	--	8220	9730	12090
CR5-1	17.0	--	--	39.6	47.7	54.7	32.8	39.5	45.3	10.6	12.8	--	8300	10000	11470
CR5-3	16.2	--	--	42.9	51.1	55.3	34.5	41.3	44.7	6.4	7.6	--	8990	10720	11600
CR6-1	14.1	--	--	40.9	47.7	53.9	35.0	40.7	46.1	10.0	11.6	--	8200	9550	10800
CR9-1	15.2	--	--	40.5	47.7	53.5	35.2	41.6	46.5	9.1	10.7	--	8800	10380	11630
CR9-3	14.1	--	--	40.8	47.6	54.1	34.7	40.3	45.9	10.4	12.1	--	8820	10270	11670
CR10-1	13.9	--	--	35.2	40.9	52.7	31.6	36.7	47.3	19.3	22.4	--	8040	9350	12050
CC3-1	21.9	--	--	37.1	47.4	51.2	35.2	45.2	48.8	5.8	7.4	--	8480	10860	11720
CC3-2	16.3	--	--	36.6	43.7	53.3	32.0	38.3	46.7	15.1	18.0	--	8160	9750	11890
CC3-3	20.2	--	--	37.3	46.7	52.6	33.6	42.2	47.4	8.9	11.1	--	8580	10750	12100
CC3-4	19.9	--	--	38.7	48.3	55.2	31.5	39.3	44.8	9.9	12.4	--	8250	10310	11770
DC1-1	14.8	--	--	37.0	43.5	48.7	39.0	45.7	51.3	9.2	10.8	--	9030	10600	11880
DC1-2	15.0	--	--	35.4	41.7	51.8	33.0	38.8	48.2	16.6	19.5	--	8150	9580	11900
FM1-2	11.8	--	--	27.1	30.8	52.6	24.5	27.7	47.4	36.6	41.5	--	5790	6570	11230
FM1-4	13.8	--	--	31.7	36.7	52.9	28.2	32.7	47.1	26.3	30.6	--	6890	7990	11500
FM1-7	13.4	--	--	36.1	41.7	50.3	35.7	41.2	49.7	14.8	17.1	--	8290	9580	11560
FM1-10	13.6	--	--	33.2	38.4	53.3	29.1	33.7	46.7	24.1	27.9	--	7090	8210	11380
FM1-13	11.2	--	--	38.7	43.6	55.1	31.5	35.5	44.9	18.6	20.9	--	8650	9740	13320
FM2-1	18.3	--	--	40.6	49.7	57.9	29.6	36.2	42.1	11.5	14.1	--	7770	9510	11080
FM2-2	13.9	--	--	43.6	50.6	56.7	33.3	38.7	43.3	9.2	10.7	--	8870	10300	11530
FM2-6	7.3	--	--	25.9	27.9	63.1	15.1	16.4	36.9	51.7	55.7	--	4570	4930	11130
FrC1-1	13.8	--	--	35.2	40.8	52.9	31.2	36.3	47.1	19.8	22.9	--	7780	9020	11710
JC2-2	14.3	--	--	36.5	42.6	45.6	43.7	50.9	54.4	5.5	6.5	--	9630	11240	12010
JC3-1	14.9	--	--	40.4	47.4	57.9	29.4	34.6	42.1	15.3	18.0	--	7320	8590	10480
JC3-5	13.7	--	--	37.8	43.8	54.6	31.3	36.3	45.4	17.2	19.9	--	7840	9090	11340
PA1-5	15.9	--	--	38.6	45.9	54.6	32.1	38.2	45.4	13.4	15.9	--	8160	9700	11540
PA1-32	16.5	--	--	43.5	52.1	59.9	29.1	34.8	40.1	10.9	13.1	--	9050	10840	12470
PA1-34	8.0	--	--	38.4	41.8	63.2	22.4	24.3	36.8	31.2	33.9	--	7360	8000	12110
PA2-1	14.9	--	--	39.1	46.0	60.5	25.6	30.0	39.5	20.4	24.0	--	7490	8780	11580
PA3-1	12.7	--	--	35.2	40.3	58.7	24.7	28.3	41.3	27.4	31.4	--	6640	7610	11080
PA3-3	15.6	--	--	35.8	42.4	56.4	27.6	32.7	43.6	21.0	24.9	--	7170	8500	11310

[a]1 - As received
2 - Moisture free
3 - Moisture and ash free

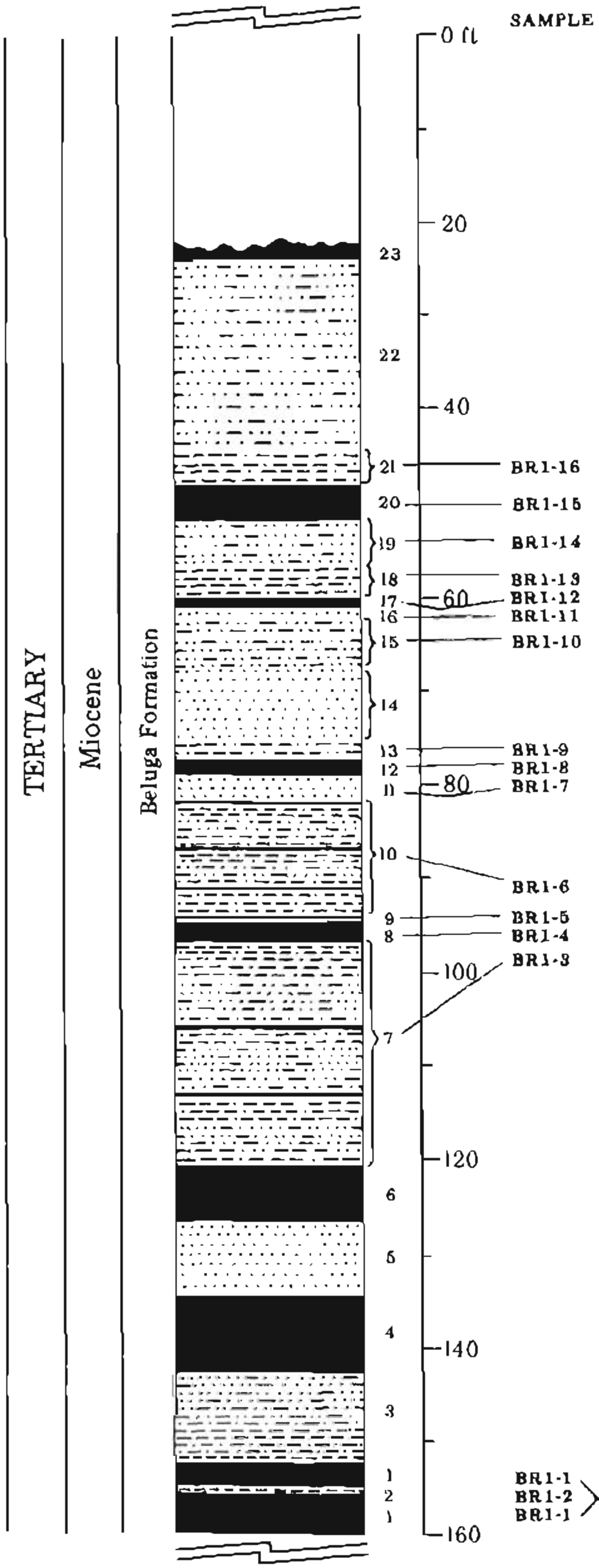
Table B-14. *Proximate analysis* (cont.)

Sample	Moisture (%)			Volatile matter (%)			Fixed carbon (%)			Ash (%)			Heating value (Btu/lb)		
	1[a]	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SC2-2	16.0	--	--	41.2	49.1	53.3	35.8	42.6	46.5	7.0	8.3	--	8510	10130	11050
SC2-3	15.6	--	--	39.4	46.7	50.3	38.9	46.1	49.7	6.1	7.2	--	9030	10690	11520
SC3-1	17.4	--	--	32.9	39.9	52.2	30.2	36.6	47.8	19.5	23.6	--	7580	9180	12010
SC4-2	16.3	--	--	40.6	48.5	53.9	34.8	41.5	46.1	8.3	10.0	--	8370	10000	11110
SC4-4	15.5	--	--	41.2	48.8	52.9	36.7	43.4	47.1	6.6	7.8	--	9010	10660	11560
SC4-7	18.1	--	--	38.8	47.4	49.0	40.3	49.2	51.0	2.8	3.4	--	9490	11580	11990
SC4-12	17.5	--	--	33.2	40.3	53.5	28.9	35.0	46.5	20.4	24.7	--	7500	9100	12080
SR1-2	14.7	--	--	31.2	36.6	49.6	31.8	37.2	50.4	22.3	26.2	--	7260	8520	11540
TR1-1	18.2	--	--	37.9	46.4	49.0	39.6	48.3	51.0	4.3	5.3	--	10960	13400	14150
WC1-3	15.2	--	--	35.3	41.6	45.9	41.6	49.1	54.1	7.9	9.3	--	9350	11020	12150
WC1-4	14.2	--	--	31.5	36.7	56.1	24.7	28.8	43.9	29.6	34.5	--	6570	7660	11700
WC2-4	15.4	--	--	32.0	37.9	52.2	29.4	34.7	47.8	23.2	27.4	--	7370	8710	12010
WC2-9	13.3	--	--	29.9	34.6	50.3	29.6	34.1	49.7	27.2	31.3	--	9240	10670	15540
WC2-10	14.9	--	--	33.3	39.1	50.3	32.9	38.7	49.7	18.9	22.2	--	8030	9430	12120
WC2-14	15.0	--	--	30.6	36.0	50.4	30.1	35.4	49.6	24.3	28.6	-	7160	8430	11800

APPENDIX C

Geologic Columns with Sampling Locations

BELUGA RIVER SEAMS
SITE: BR1



LITHOLOGIC DESCRIPTION

23 Coal (inaccessible); section discontinued.

22 Sandstone, clayey, medium-gray (N5), medium-grained, firm.

21 Claystone, slightly sandy, light-olive-gray (5Y6/1), streaked olive-gray (5Y4/1), firm.

20 Coal, brownish-black, dull, bony, hard.

19 Sandstone, slightly clayey, olive-gray (5Y4/1) with grayish-black (N2) coaly inclusions, medium-grained with disseminated, very fine muscovite, friable.

18 Claystone, slightly sandy, light-olive-gray (5Y6/1) with medium-olive-gray (5Y5/1) to olive-gray (5Y4/1) streaks, finely disseminated black organic matter and thread-like stringers of coal, locally iron-oxide-stained.

17 Coal, black, dull, platy, bony, hard.

16 Sandstone, light-olive-gray (5Y6/1) with black (N1) coaly inclusions, medium-grained, organic, firm.

15 Sandstone, clayey, light-olive-gray (5Y5/1), medium-grained, disseminated black organic matter and fine muscovite, locally friable.

14 Sandstone, medium-gray (N5), medium- to coarse-grained, abundant disseminated black organic matter ("salt and pepper"), friable, soft.

13 Claystone, sandy, light-olive-gray (5Y6/1) with pale yellowish-orange (10YR8/6) mottling, firm but weathered soft locally.

12 Coal, black, dull, platy, hard, bony.

11 Sandstone, medium-olive-gray (5Y5/1), speckled white (N9) and black (N1), organic, medium-grained, hard with coal spars at top; below sandstone, medium gray (N5), medium grained, weathered, friable, soft.

10 Claystone, sandy, medium-olive-gray (5Y5/1) with olive-black (5Y2/1) streaks, predominantly, and sandstone, clayey, medium-gray (N5), medium-grained, firm, interbedded with few thin (less 0.5 ft) coal stringers.

9 Shale, carbonaceous, brownish-gray (5Y4/1), firm to hard, iron-rich, slightly fissile.

8 Coal, black, dull, hard, bony.

7 Claystone, sandy, medium-olive-gray (5Y5/1) with fine brownish-black (5YR2/1) coaly inclusions, firm, predominantly, but interbedded with sandstone, clayey, medium-gray (N5), medium-grained, locally weathered and friable, and thin (less 0.5 ft) coal stringers.

6 Coal (inaccessible).

5 Sandstone, medium-gray, medium- to coarse-grained, friable, firm.

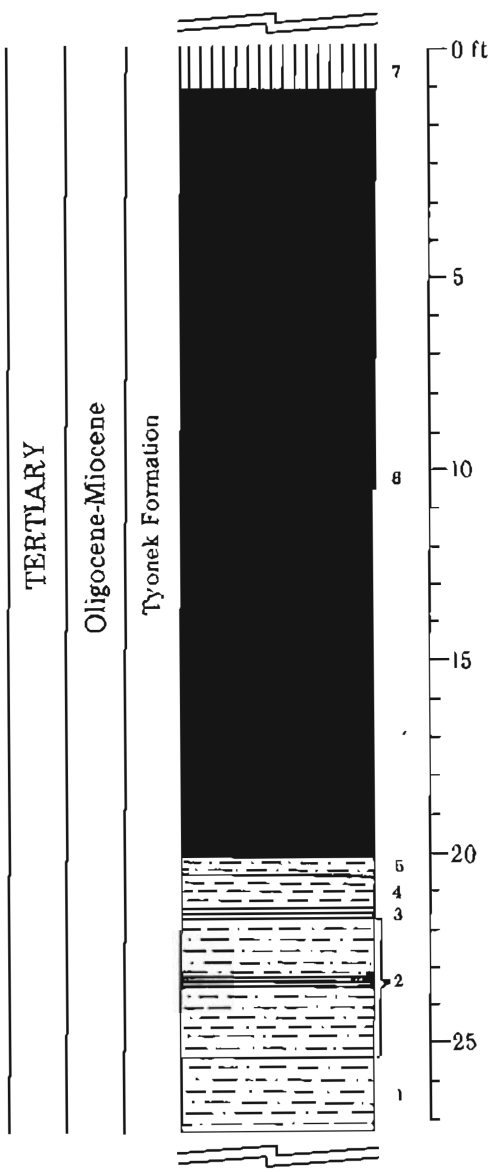
4 Coal (inaccessible).

3 Claystone, sandy, medium-gray, firm, and sandstone, clayey, medium-gray, medium-grained, soft to firm interbedded.

2 Parting, claystone, sandy, brownish-gray (5YR4/1) with dark-gray (N3) coaly inclusions, firm.

1 Coal, black, dull, platy, woody, locally bony.

CANYON CREEK SEAM
SITE CnC5



SAMPLE

CnC5-1
CnC5-2
CnC5-3
CnC5-4

LITHOLOGIC DESCRIPTION

7 Roof covered and inaccessible.

6 Canyon Bed; coal, black, dull, blocky with few vitrain bands, hard; locally platy and ashy.

SEATROCK

5 Claystone, sandy, olive-black (5Y/1), carbonaceous, firm.

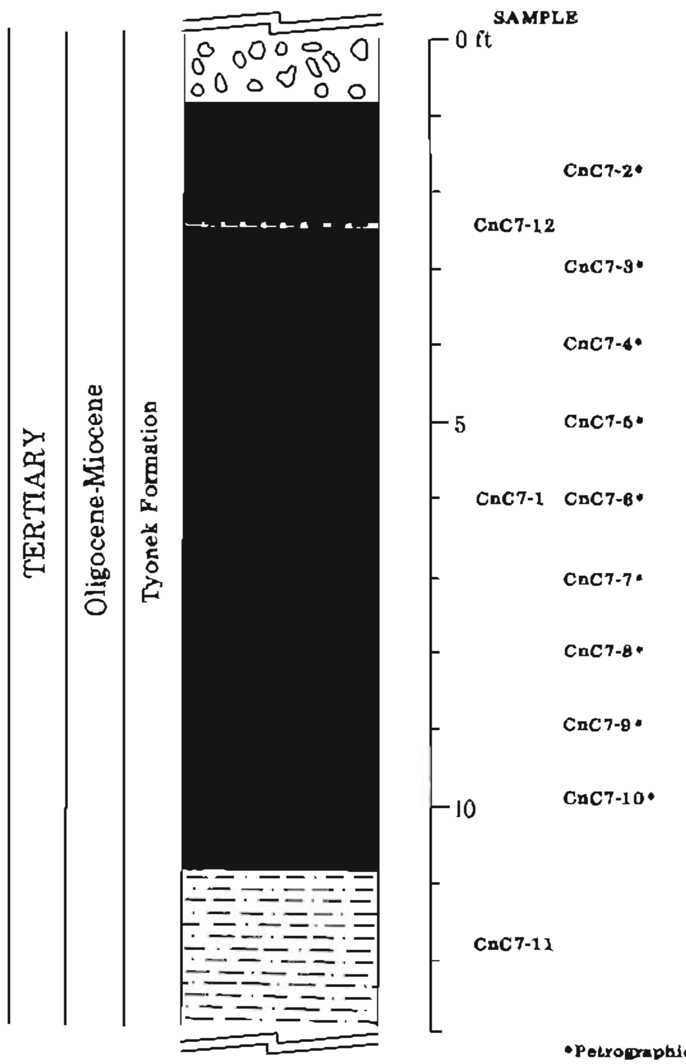
4 Claystone, pinkish-gray (5YR8/1) with grayish-black (N2) to black (N1) coaly inclusions, locally carbonaceous, rooted, weathered and soft.

3 Shale, carbonaceous, black (N1), fissile, highly weathered, soft.

2 Claystone, slightly sandy, pinkish-gray (5YR8/1) with grayish-black (N2) coaly inclusions and black (N1) disseminated organic matter, firm; 0.2 ft band of shale, carbonaceous, black (N1), fissile, highly weathered and soft in center of unit.

1 Claystone, slightly sandy, pinkish-gray (5YR8/1) with black (N1) coaly inclusions and local dark-yellowish-orange (10YR6/6) mottling, firm.

CANYON CREEK SEAM
SITE CnC7



*Petrographic sample

LITHOLOGIC DESCRIPTION

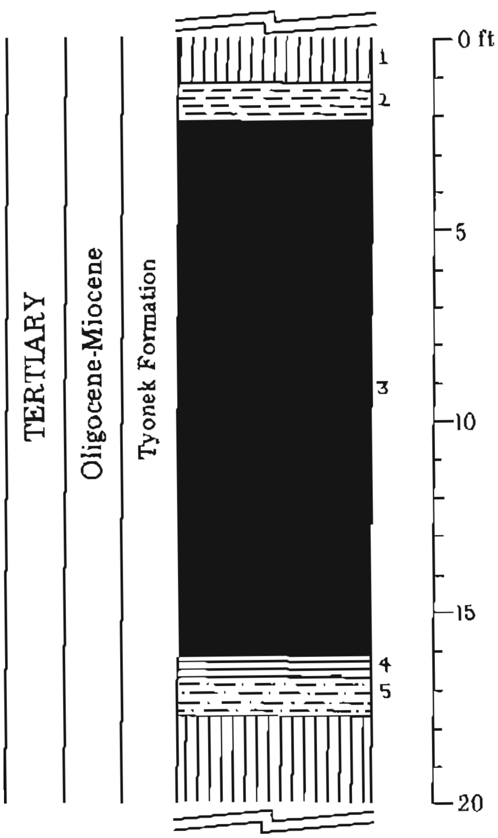
Boulders (diamicton) up to several feet in diameter.

Parting, claystone (possibly volcanic ash), pale-yellowish-orange (10YR8/6) to dark-yellowish-orange (10YR6/6), firm.

Coal, black, dull, very hard, platy, with distinctive surficial-weathering pattern similar to drusy quartz in appearance.

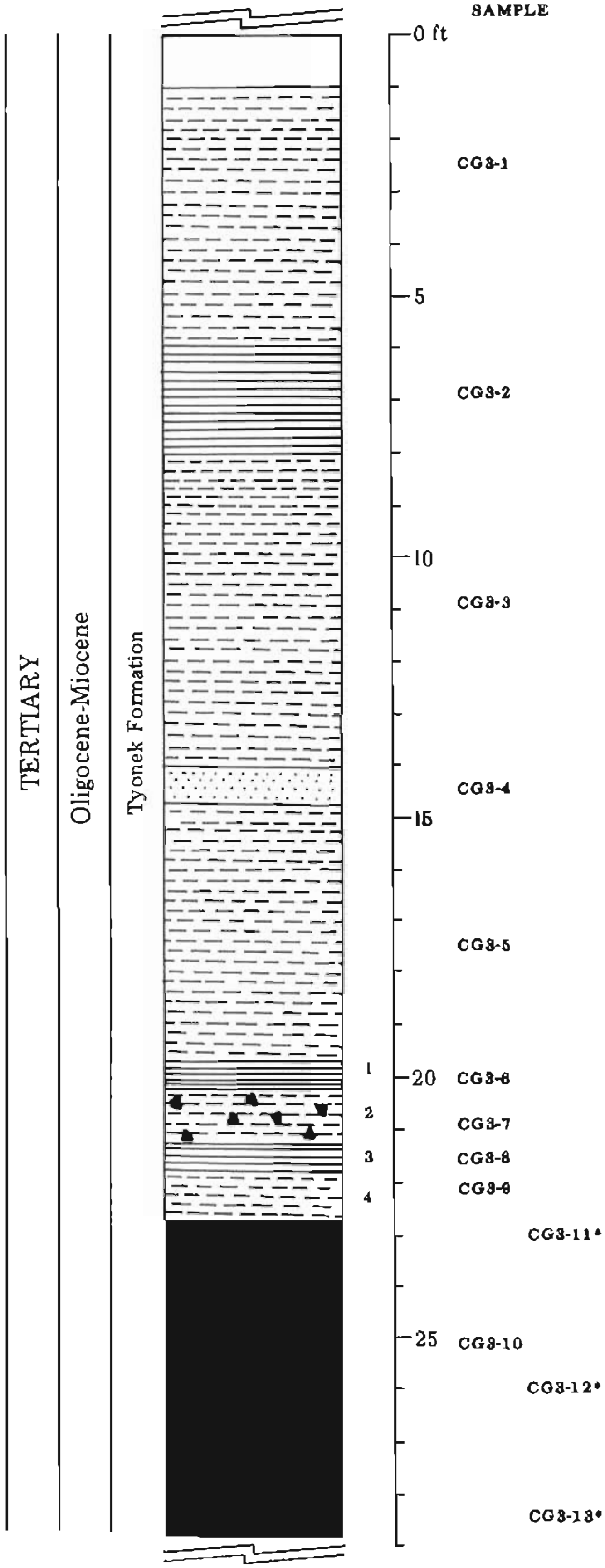
SEATROCK (underclay): claystone, slightly sandy, light-olive-gray (5Y6/1) with dark-yellowish-brown (10YR4/2) organic inclusions, carbonaceous plant fragments, micaceous, firm.

CANYON CREEK SEAM
SITE CnC8



SAMPLE	LITHOLOGIC DESCRIPTION
	1 Covered interval directly above roof but includes boulders (diamicton) to several feet in diameter toward top of section.
CnC8-1	2 Roof: claystone, slightly sandy, olive-gray (5Y4/1), carbonaceous, soft
CnC8-2	3 Coal, black, dull, blocky, hard, quality of coal deteriorates significantly in basal 2-3 ft.
	SEATROCK
CnC8-3	4 Shale, carbonaceous, brownish-black (5YR2/1), soft, smutty.
CnC8-4	5 Claystone, sandy, light-olive-gray (5Y6/1), slightly carbonaceous, especially toward top, micaceous, soft to firm.

CAPPS COAL SEAM
SITE CG3



LITHOLOGIC DESCRIPTION

Surficial cover; predominantly a brown sandy loam.

Claystone, olive-black (5Y2/1) to brownish-gray (5YR4/1), carbonaceous, breaks with blocky conchoidal fracture, firm, locally has pale-yellowish-orange (10YR8/6) to light-brown (5YR5/6) goethite staining along weathered surfaces and fracture planes.

Shale, carbonaceous, brownish-black (5YR2/1) to olive-black (5Y2/1) to grayish-black (N2), firm to soft, locally fissile with thin interbedded lenses (less 1 in.) of sandstone, medium-gray (N5), coarse-grained, and coal (approximately 1 in. thick), black, bony, platy, soft and weathered.

Claystone, slightly sandy to sandy, medium-gray (N5), massive, firm, blocky conchoidal fracture and abundant iron-oxide staining along fracture planes and weathering surfaces.

Sandstone, light-olive-gray (5Y6/1) to medium-olive-gray (5Y5/1), coarse-grained, very hard, calcareous, with abundant plant-leaf fossils, pale-yellowish-orange (10YR8/6) iron-oxide staining along central (2 in. thick) band.

Claystone, olive-black (5Y2/1), massive, firm, with abundant black, carbonaceous, fossil-leaf films, locally with moderate-red (5R4/6) to dusky-red (5R3/4) hematitic oxidation staining.

1 Shale, black (N1) to brownish-black (5YR2/1), slightly carbonaceous, fissile, soft to firm, locally highly weathered.

2 Claystone, moderate-brown (5YR3/4) with black (N1) coaly inclusions, soft to firm, breaks with conchoidal fracture, rounded limonite on hematite nodules to 2 in. diameter, thin streaks and contorted laminae of black carbonaceous shale.

3 Shale, carbonaceous, black (N1) with light-brown (5YR5/6)-weathering stains, fissile, soft.

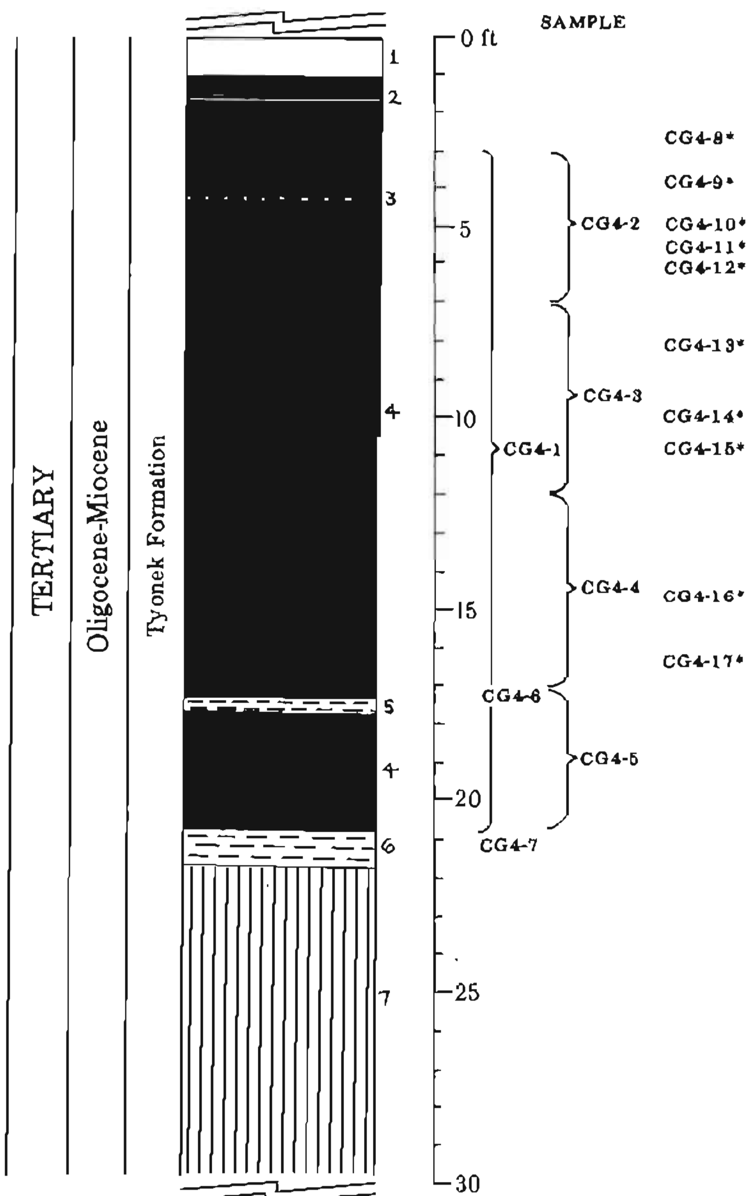
4 Claystone, olive-gray (5Y4/1) to olive-black (5Y2/1), firm to soft, with blocky fracture pattern.

Capps Seam: coal, black, dull, firm to hard, locally with thin (less 3 in.) vitrain bands, surfaces and fractures covered with abundant iron-oxide and sulfate stains, local siderite.

*Petrographic sample

CAPPS SEAM
SITE CG4

LITHOLOGIC DESCRIPTION



1 Surficial cover; unconsolidated light-brown sand and sandy loam.

2 Coal (top 2 ft), black, soft, highly weathered, and shale, carbonaceous, black (N1), fissile, firm.

3 Parting, claystone, dark-gray, carbonaceous, soft.

4 Capps Seam; coal, black, predominantly dull and blocky but locally bony and platy with increasing vitrain bands toward basal portion.

5 Parting: claystone (possibly volcanic ash), light-brownish-gray (5YR6/1), firm.

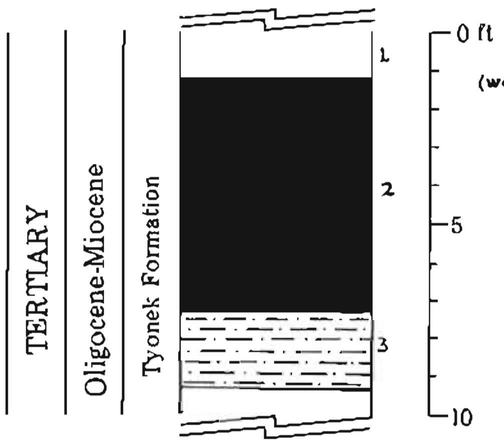
SEATROCK (underclay)

6 Claystone, medium-olive-gray (5Y5/1) with grayish-black (N2) carbonaceous inclusions, locally slightly fissile, soft to firm.

7 Section down to level of Capps Creek largely covered with talus and regolith but predominantly sandstone, medium-gray (N5), medium-grained, friable but firm, and claystone, sandy, medium-gray (N5), soft to firm, breaks with conchoidal fracture.

*Petrographic sample

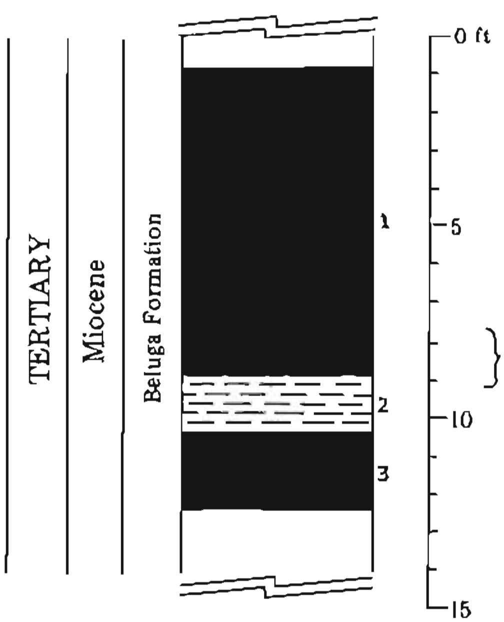
CHUITNA RIVER SEAM
SITE CR3



SAMPLE		LITHOLOGIC DESCRIPTION
CR3-3 (weathered clay)		[1] Baked shale and varicolored clays weathering from it.
CR3-1	CR3-1p*	[2] Chuitna Bed (partial exposure, basal portion); coal, black, dull, blocky, highly weathered.
CR3-2		[3] SEATROCK (underclay) Claystone, sandy, medium-light-gray (N6), black carbonaceous leaf impressions, soft.

Section discontinued at water level.

CHUITNA RIVER SEAM
SITE CR5

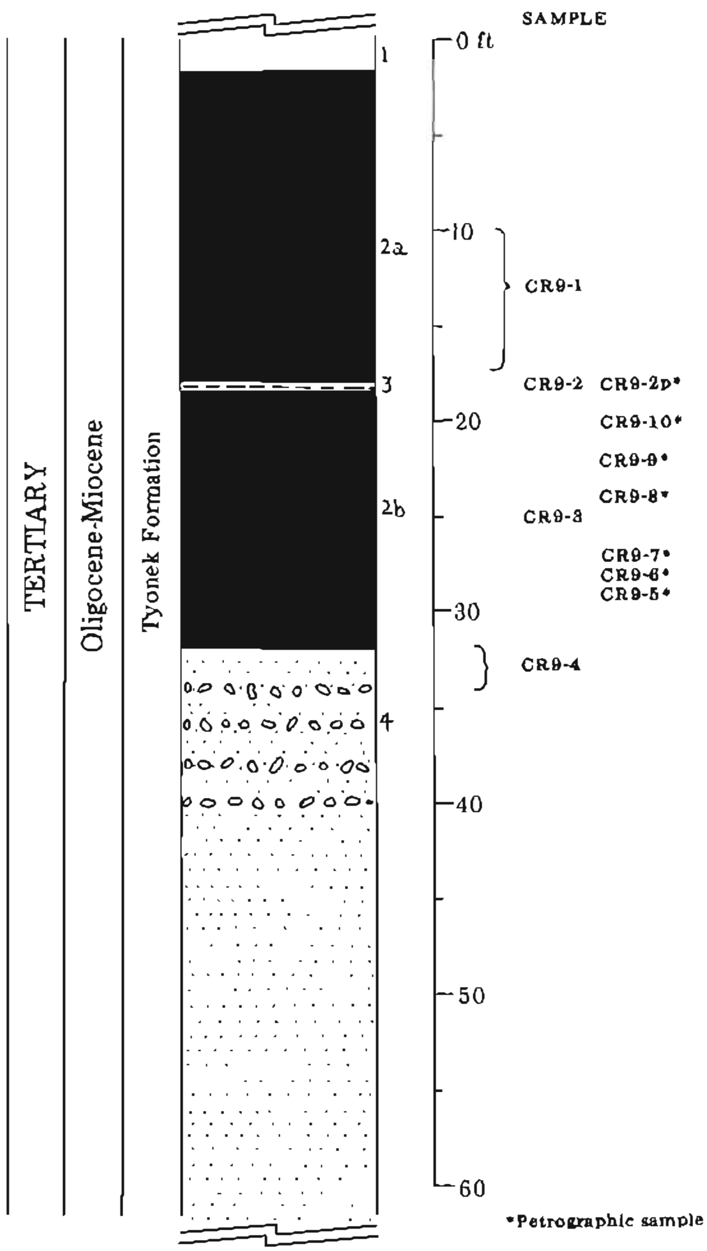


SAMPLE		LITHOLOGIC DESCRIPTION
		[1] Coal, black, dull, blocky, highly weathered with abundant orange-limonite staining.
CR5-1	CR5-1p*	
CR5-2		PARTING [2] Claystone, light-olive-gray (5Y6/1), locally carbonaceous, iron-oxide staining, firm.
CR5-3	CR5-3p*	[3] Coal, black, dull, blocky, hard.

Section discontinued at creek level.

*Petrographic sample

CHUITNA RIVER SEAM
SITE CR9



LITHOLOGIC DESCRIPTION

1 Roof of coal inaccessible.

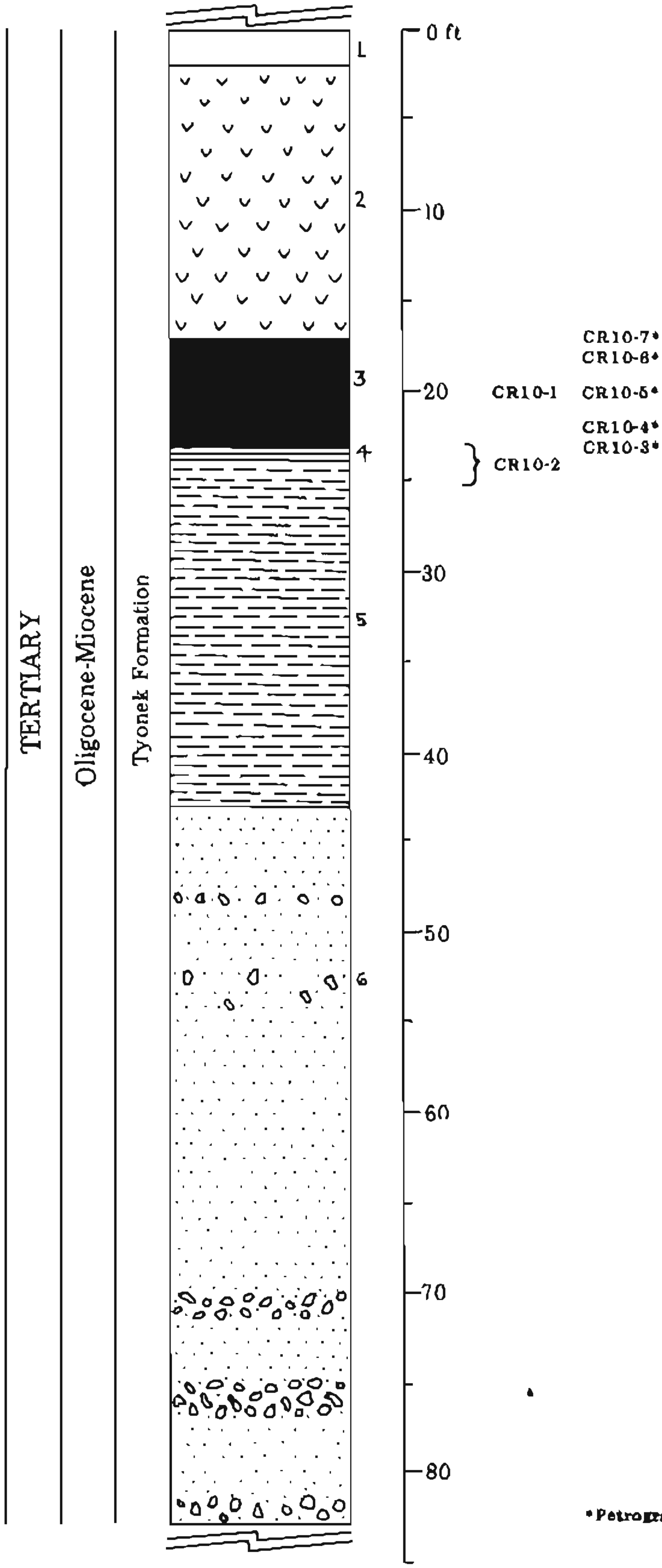
2a Chuitna Bed: coal, black, hard, platy, dull, locally bony.

3 Parting (possibly volcanic ash); claystone, silty, olive-black (5Y2/1), weathers to grayish-red (10R4/2), firm, breaks with conchoidal fracture.

2b Coal below parting predominantly dull and blocky, ash content appears significantly less than in upper portion; local minor pyrite and weathered-sulfate coatings.

4 SEATROCK
Sandstone, light-olive-gray (5Y6/1) to pinkish-gray (5YR8/1), medium-grained, relatively clean, predominantly quartz with disseminated black organic matter, subrounded to angular grains, friable, weathered, soft. Minor (near 0.5 ft) partings of quartz-pebble conglomerate and conglomeratic sandstone toward top of section beneath coal bed.

CHUITNA RIVER SEAM
SITE CR10



LITHOLOGIC DESCRIPTION

1 Surficial cover; brown sandy loam, sand, and gravel.

2 Burn (clinker, "red dog," scoria, porcellanite).

3 Coal, predominantly dull and blocky with thin (less 2 in.) vitrain bands and bony layers (to 0.5 ft), hard.

4 Shale, carbonaceous, olive-gray (5Y4/1) with light-brown (5YR5/6)-oxidation staining, firm.

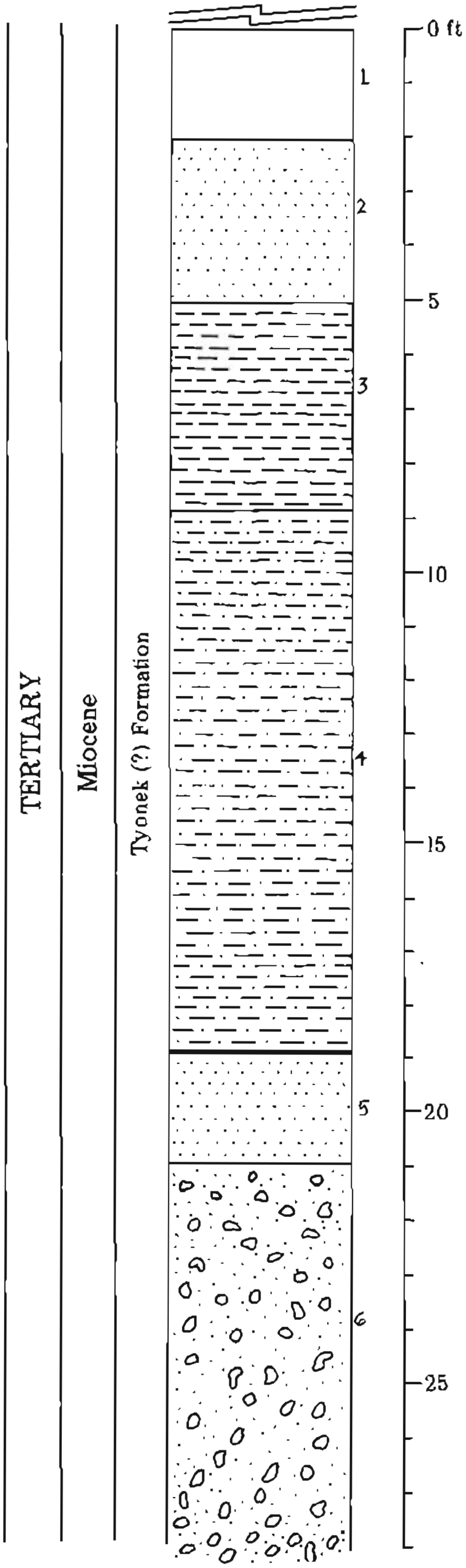
5 Claystone, dark-gray (N3), carbonaceous, soft, locally weathered with light-brown (5YR5/6)-limonite staining.

6 Sandstone, medium-gray (N5), medium- to coarse-grained, locally conglomeratic with interbedded quartz-pebble-conglomerate bands, especially toward the basal portion of outcrop and light-brown (5YR5/6)-iron-oxide staining.

*Petrographic sample

FAIRVIEW MOUNTAIN SEAMS
SITE FM1

Sheet 1 of 7



LITHOLOGIC DESCRIPTION

1 Surficial cover; loam, sand, brown, disseminated black-organic matter, soft, rooted.

2 Sand, yellowish-gray, medium-grained, slightly clayey, soft, yellow- to orange-iron-oxide mottling, rare extremely fine disseminated muscovite.

3 Claystone, light-gray, soft, with abundant yellow-iron-oxide staining.

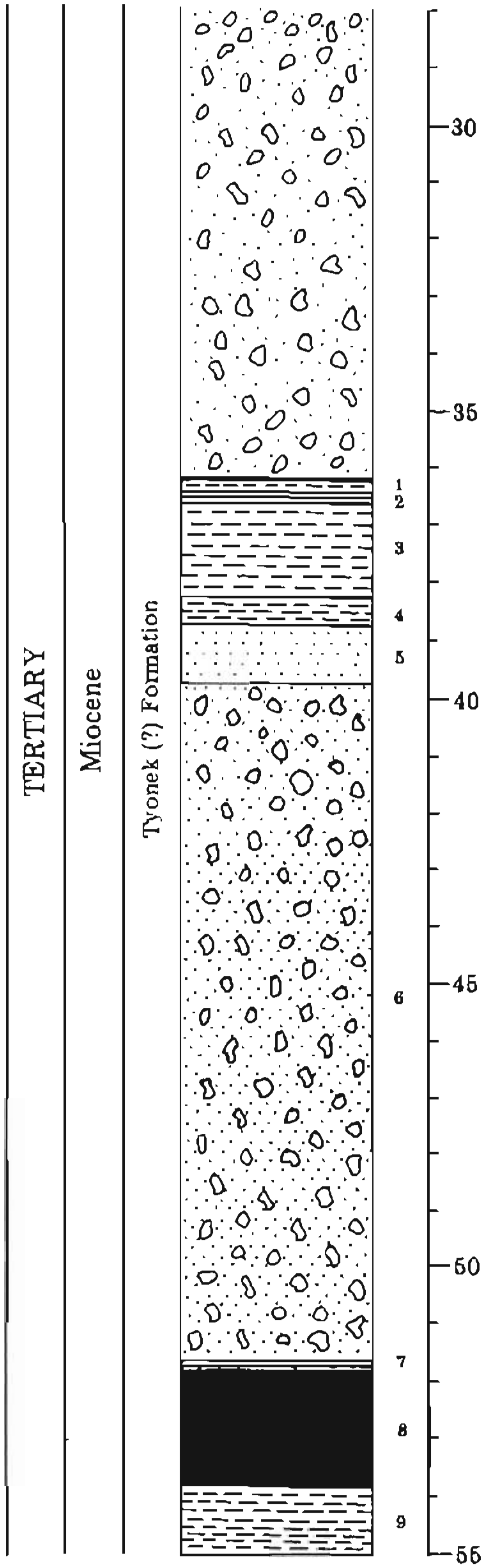
4 Claystone, sandy, medium-gray, fine disseminated muscovite and black organic matter, firm; thin (1 in.) stringer of coal, black, dull, very hard, forming base.

5 Sand, yellowish-gray, coarse-grained, locally contains disseminated organic matter and abundant threadlike stringers of black carbonaceous material, weathered, loose.

6 Conglomerate, petromictic, light to medium-gray; sand matrix, coarse-grained, angular fragments, poorly cemented to loose, predominantly quartz and chert; "gravel" mostly in size range less 0.5 ft and includes various igneous lithologies, coal gravels, and cobbles; interspersed within unit are thin (less 2 in.) stringers and pockets of clay, light- to medium-gray, soft, plastic. Thin coal stringer (less 1 in.) at base of conglomerate.

FAIRVIEW MOUNTAIN SEAMS
SITE FM1

Sheet 2 of 7



SAMPLE

FM1-1 FM1-2a*
FM1-2 FM1-2b*
FM1-2c*
FM1-3

*Petrographic sample

LITHOLOGIC DESCRIPTION

1 Claystone, dark-gray, slightly sandy, carbonaceous, firm.

2 Shale, carbonaceous, black, fissile, soft to firm, weathered.

3 Claystone, medium-brownish-gray, slightly carbonaceous and sandy, firm.

4 Claystone, medium-gray, very sandy, firm.

5 Sand, medium-gray, medium- to coarse-grained with abundant limonitic and hematitic staining and black coaly stringers and bands.

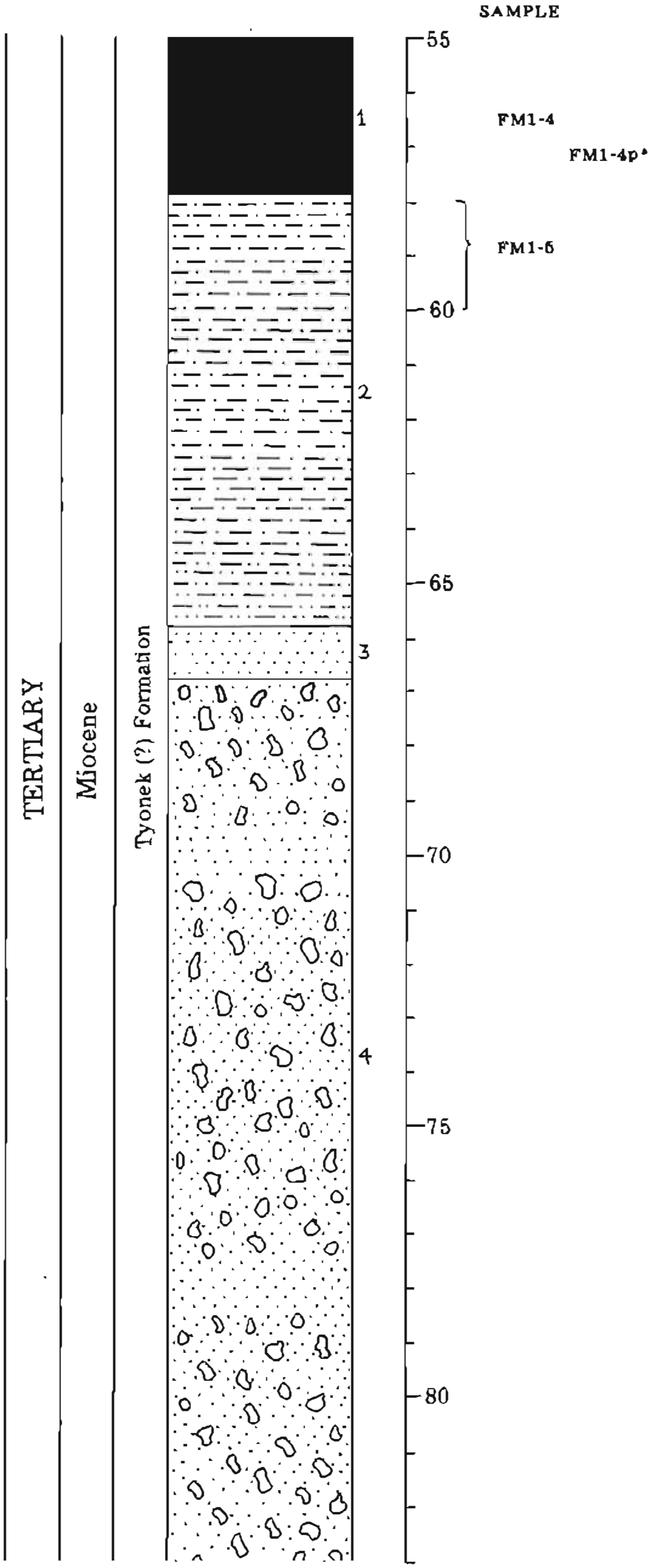
6 Conglomerate, petromictic (as above) but with abundant coal cobbles and gravel inclusions; few graphite nodules to 0.5 ft diameter near base directly above coal; also contains few clean orthoquartzite-sandstone cobbles.

7 Shale, carbonaceous, black (N1), fissile, firm, weathered with abundant iron-oxide staining.

F Seam

8 Coal, black, dull, platy, ashy, weathered, poor-quality.

9 Partings, claystone, olive-black (5Y 2/1), carbonaceous, slightly sandy, firm, thin (less 2 in.) coal bed in basal portion.



LITHOLOGIC DESCRIPTION

F Seam

1 Coal, black, dull, platy, bony, poor quality with thin laminae of claystone, sandy, medium-gray, soft and shale, carbonaceous, black, fissile, soft, intercalated for top 2 ft; lower 0.5 ft dull, blocky, hard coal.

SEATROCK (underclay)

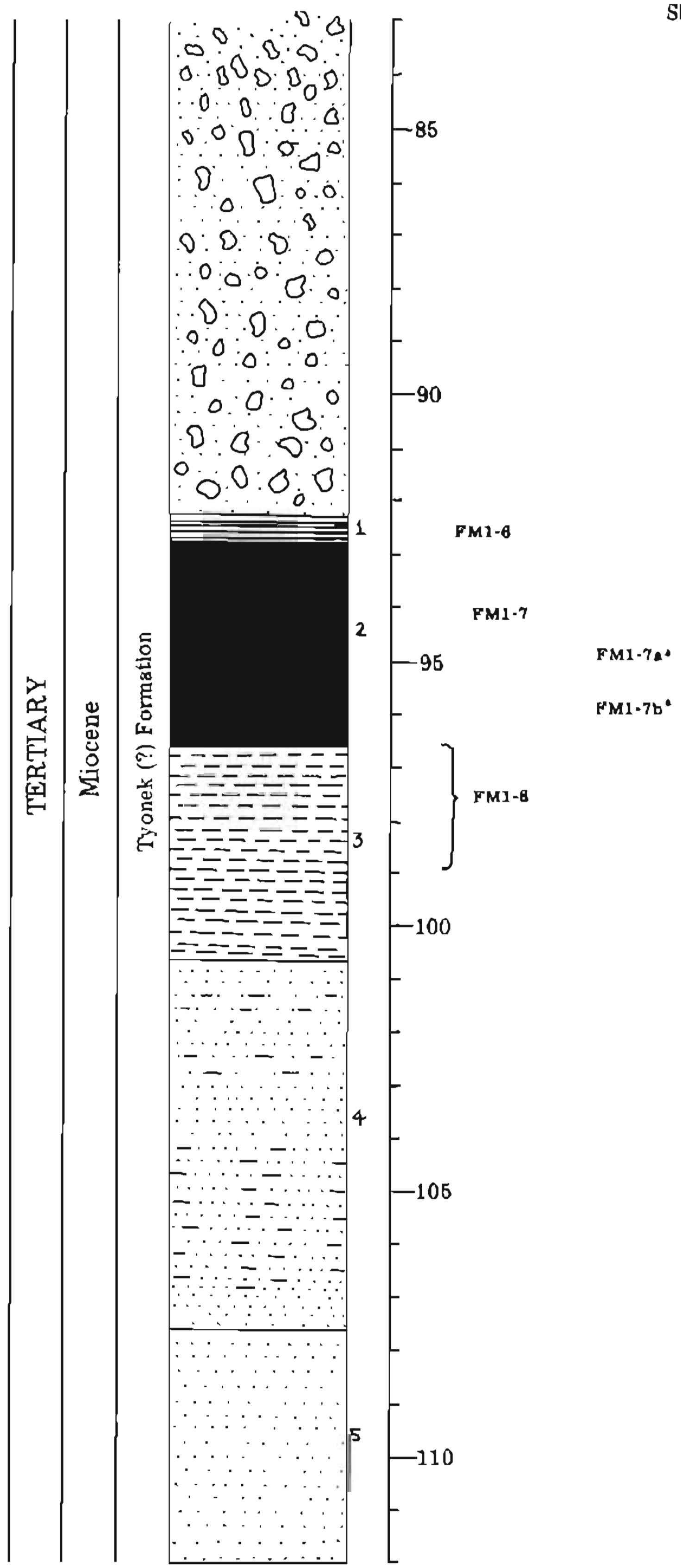
2 Claystone, sandy, medium-light (N6)-gray, firm, limonite surface stains, breaks with conchoidal fracture; becomes more sandy toward basal portion with few interspersed sand lenses (less 1 in.), light- to medium-gray, medium-grained, micaceous, locally limonite-stained.

3 Sand, yellowish-gray, fine- to medium-grained, soft, loose with disseminated fine black organic matter and muscovite; also smutty coal stringers (around 0.5 in.) locally.

4 Conglomerate, petromictic pebble-cobble, with coarse-grained, poorly lithified sand matrix; pebbles and cobbles predominantly 2 in. to less than 0.5 ft of various igneous lithologies (including granite), abundant coal, quartz, chert, and clean orthoquartzite sandstone; pebbly sandstone lenses to 1 ft thick locally throughout this section.

*Petrographic sample

FAIRVIEW MOUNTAIN SEAMS
SITE FM1



LITHOLOGIC DESCRIPTION

1 Shale, carbonaceous, black (N1) with light-brown (5YR5/6) weathering stains, fissile, firm.

E Scam
2 Coal, top 2 ft, black, dull, platy, weathered, firm; basal portion dull, blocky, bony, hard.

SEATROCK (underclay)
3 Claystone, olive-gray (5Y4/1) with black (N1) coaly inclusions and local light-brown (5YR5/6) mottling, firm, breaks with conchoidal fracture.

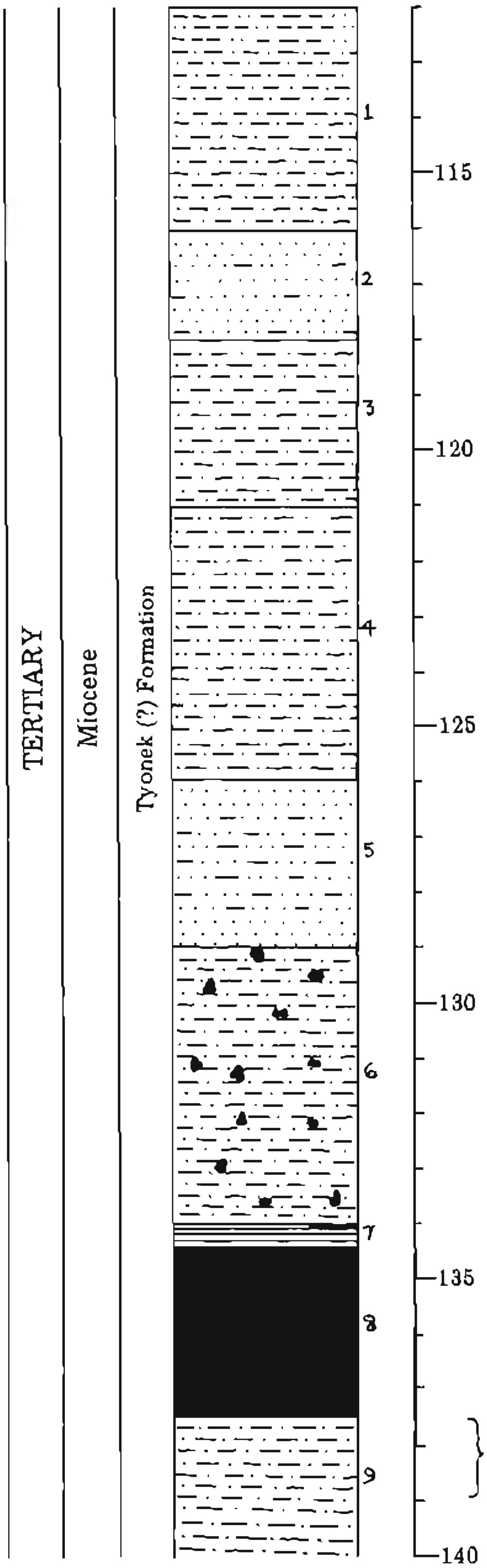
4 Sandstone, medium-gray, fine-grained, friable, slightly clayey, with fine disseminated muscovite and black organic fragments.

5 Sand, medium-gray, medium-grained, loose, soft with disseminated, extremely fine muscovite and black organic matter, locally limonite-stained.

*Petrographic sample

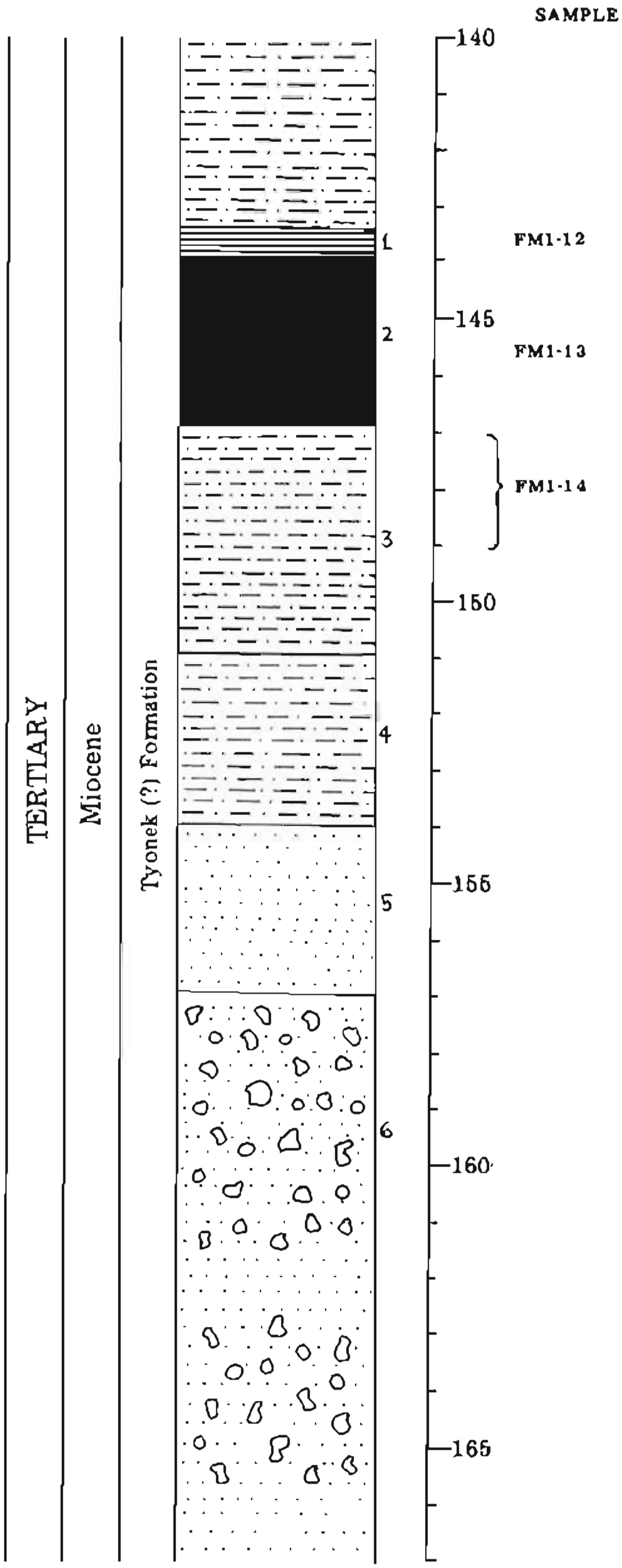
FAIRVIEW MOUNTAIN SEAMS
SITE FM1

Sheet 5 of 7



SAMPLE		LITHOLOGIC DESCRIPTION
		1 Claystone, sandy to very sandy, medium-gray, firm with abundant limonite staining.
		2 Sand, light- to medium-gray, fine- to medium-grained, slightly clayey, soft, with disseminated fine muscovite flakes and black organic matter.
		3 Claystone, sandy, medium-grayish-brown, firm, local iron-oxide staining.
		4 Claystone, very sandy, light-gray, firm.
		5 Sandstone, clayey, light-gray, medium-grained, friable soft, with fine disseminated black organic matter and coaly streaks.
		6 Claystone, sandy, light-gray, firm, with weathered ironstone nodules to 2 in. diameter.
FM1-9		7 Shale, carbonaceous, dark-gray (N3) to black (N1), clayey, fissile, soft.
	FM1-10a*	
FM1-10	FM1-10b*	D Seam 8 Coal, black, dull, hard, platy, bony.
	FM1-10c*	
FM1-11		SEATROCK (underclay) 9 Claystone, sandy, olive-gray (5Y4/1) with grayish-black (N2)-threadlike stringers, firm, breaks with conchoidal fracture, locally limonite-stained.

*Petrographic sample



LITHOLOGIC DESCRIPTION

ROOF
1 Shale, carbonaceous, brownish-black (5YR2/1), fissile, weathered, soft.

C Seam
2 Coal, black, dull, hard, blocky at top to bony and platy at basal portion

SEATROCK (underclay)
3 Claystone, very sandy, light-olive-gray (5Y6/1), firm.

4 Claystone, sandy, medium-gray, firm, with very fine disseminated muscovite.

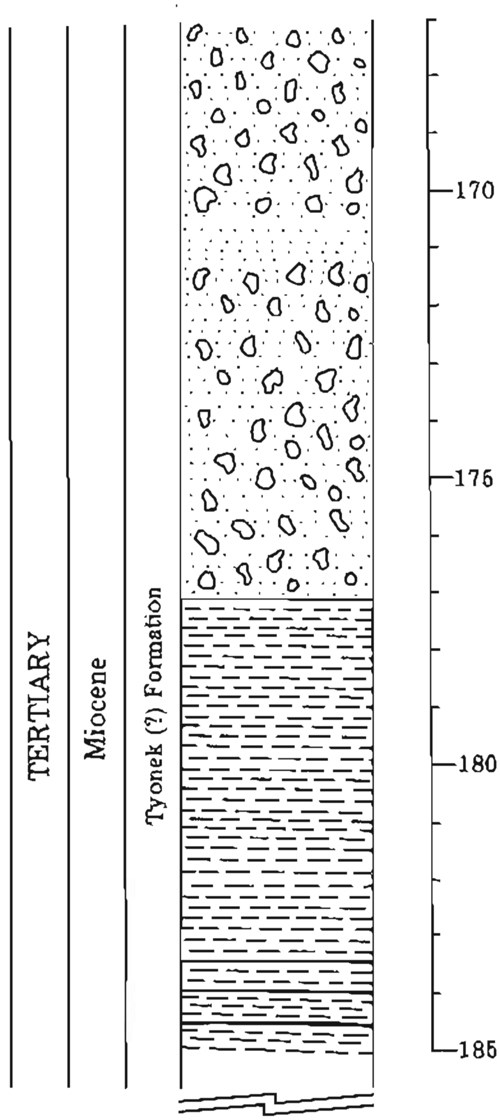
5 Sand, medium-gray, very coarse-grained, angular to subangular grains, disseminated black fine coal fragments, friable, loose, weathered.

6 Conglomerate, petromictic, pebble-cobble (including coal); sand matrix, very coarse-grained, poorly lithified with fine disseminated coal fragments; local coarse-grained pebbly sand layers up to 1 ft thick.

FAIRVIEW MOUNTAIN SEAMS
SITE FM1

Sheet 7 of 7

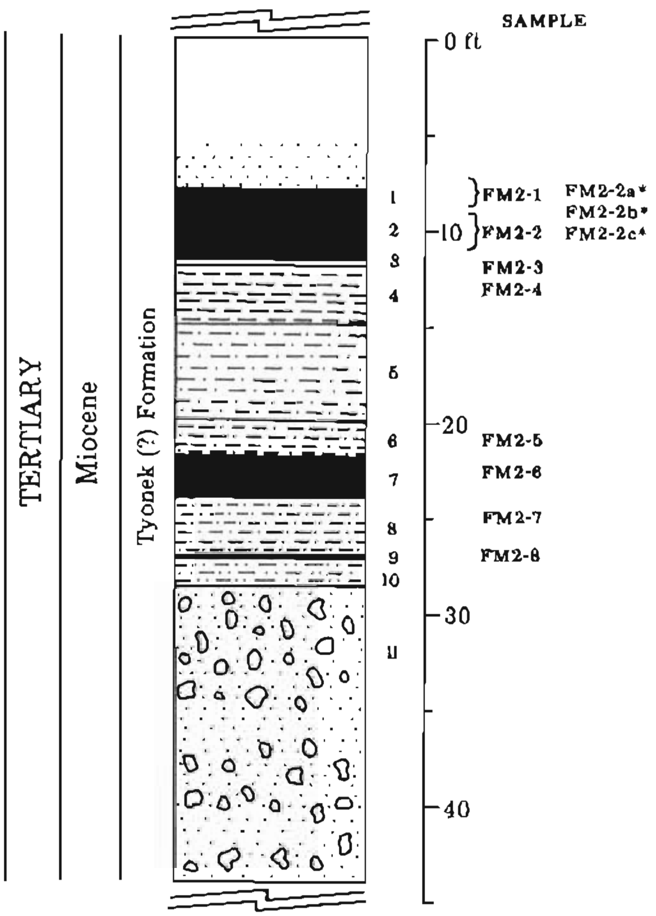
LITHOLOGIC DESCRIPTION



Claystone, medium-gray but grades to dark-gray and carbonaceous in basal portion, soft to firm; pockets and stringers of coal near bottom.

Section discontinued but remaining section includes two poorly exposed and highly weathered coal seams (A and B); see FM2.

FAIRVIEW MOUNTAIN SEAMS
SITE FM2



LITHOLOGIC DESCRIPTION

Surficial cover predominantly a sandy loam grading to sand at base.

B Seam

1 & 2 Coal, top 0.5 ft black, very soft, smutty; bottom 3 ft very hard and bony, breaks blocky and locally with conchoidal fracture.

3 Shale, carbonaceous, brown, black (5Y2/1), clayey, soft.

4 Claystone, olive-gray (5Y4/1) with moderate-brown (5YR4/4) plant-fragment inclusions, slightly silty, soft to firm.

5 Claystone, sandy, light-gray, soft, with very fine disseminated muscovite.

6 Claystone, medium-gray (N5) with black (N1) inclusions and dark-yellowish-orange (10YR6/6) mottling, slightly sandy and carbonaceous, firm.

A Seam

7 Coal, black to brownish-black, lignitic toward base, poor quality; thin (less 1 in.) partings of claystone, brown, firm, and shale, carbonaceous, black, fissile, firm, toward top.

8 Claystone, sandy, olive-gray (5Y4/1) with grayish-brown (5YR3/2) and blackish-red (5R2/2) plant-fragment inclusions, disseminated extremely fine muscovite, firm.

9 Coal stringer, black, hard, woody.

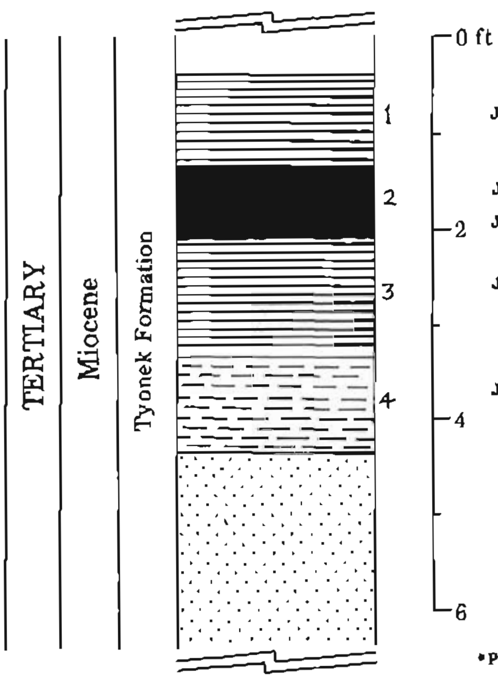
10 Claystone, very sandy, medium-gray (N5), extremely fine disseminated muscovite, firm.

11 Conglomerate, petromictic, pebble-cobble; pebbles, gravels, and cobbles predominantly less than 3 in. in diameter consisting of quartz, chert, orthoquartzite sandstone, coal, and granite in a poorly lithified, coarse-grained, sand matrix; also includes pebbly, coarse-grained-sand intervals to several feet thick, yellowish-gray, angular to subangular with disseminated black organic matter.

Section described down to level of Cottonwood Creek.

*Petrographic sample

JOHNSON CREEK SEAM
SITE JC2

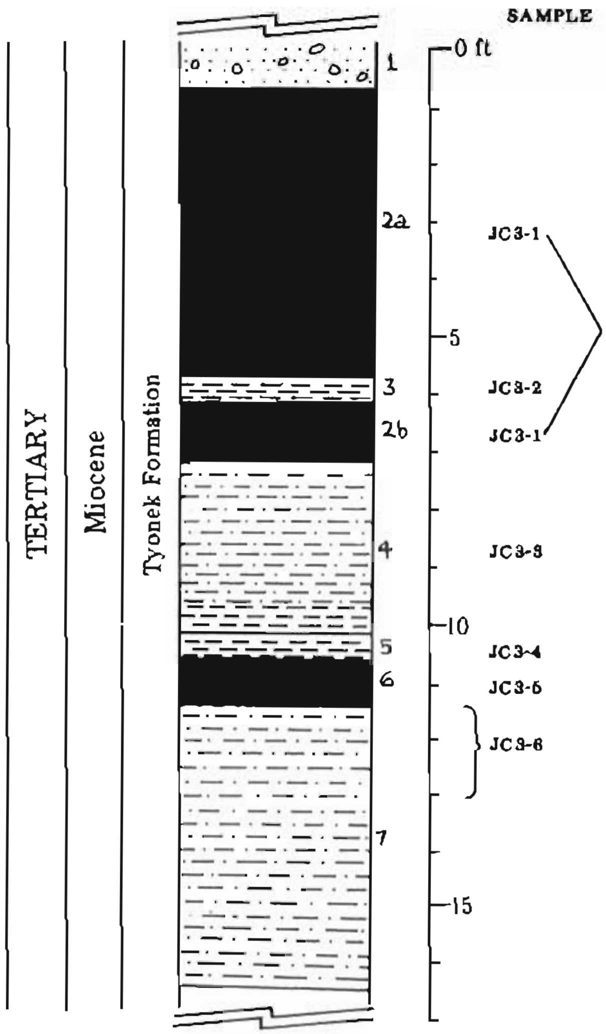


LITHOLOGIC DESCRIPTION

SAMPLE	
	Section includes 50-ft ledge of sandstone, conglomerate, two other thin coal beds, gravel, and surficial cover.
JC2-1	1 Shale, carbonaceous, black, hard, fissile, local iron-oxide staining.
JC2-2 JC2-2p*	2 Coal, black, very hard, bright, glassy fracture, semianthracitic, conchoidal fracture.
JC2-3	3 Shale, carbonaceous, olive-black (5Y2/1) to black (N1), fissile, firm.
JC2-4	4 Claystone, olive-black (5Y2/1) with black (N1) coaly stringers, firm. Approximately 8 ft of claystone is followed downsection to creek level by sandstone, medium-gray, medium-grained, hard.

*Petrographic sample

JOHNSON CREEK SEAMS
SITE JC3



LITHOLOGIC DESCRIPTION

1 Overburden section of approximately 30 ft of pebbly sandstone, conglomerate, and unconsolidated surficial cover, locally highly washed and eroded with covered intervals.

2a Coal, black, dull, hard, bony, locally platy and weathered with iron-oxide staining.

3 Parting: claystone, light-brownish gray (5YR6/1) with dark-gray (N3) carbonaceous inclusions and coal stringers, firm.

2b Coal as above.

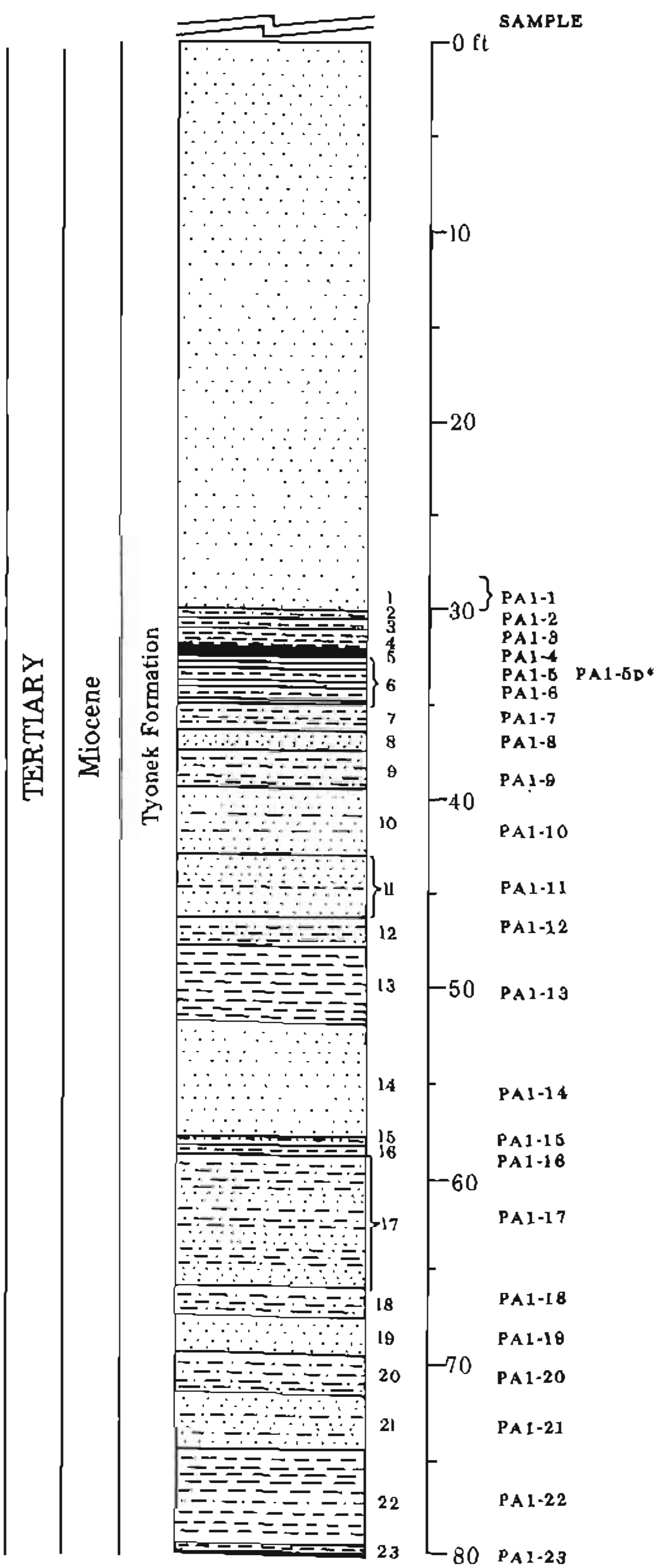
4 Claystone, sandy, light-olive-gray (5Y6/1) with olive-black (5Y2/1) carbonaceous inclusions and dark-yellowish-orange (10YR6/6) mottling; becomes less sandy and more silty toward base.

5 Claystone, dark-yellowish-brown (10YR4/2) with dark-gray (N3) carbonaceous stringers and dark-yellowish-orange (10YR6/6) mottling, firm.

6 Coal, black, hard, dull, bony, platy.

7 Claystone, sandy, light-olive-gray (5Y6/1) with black (N1) coaly inclusions and local dark-yellowish-orange (10YR6/6) mottling, firm.

PETERSVILLE AREA SEAMS
SITE PA1
Sheet 1 of 3



*Petrographic sample

LITHOLOGIC DESCRIPTION

1 Sandstone and sand, light-olive-gray (5Y6/1) with black (N1) coaly inclusions and local pale-yellowish-orange (10YR8/6) mottling, coarse-grained, angular to subrounded, predominantly quartz but arkosic, weathered, friable, soft.

2 Claystone, sandy, moderate-yellowish-brown (10YR5/4) dark-yellowish-orange (10YR6/6) and pale-yellowish-orange (10YR8/6) streaked, soft to firm, with distinctive gravels of brown amber and coalified wood laths.

3 Clay, light-olive-gray (5Y6/1), very soft, plastic, pliable.

4 Claystone, medium-gray (N5) with grayish-black (N2) coaly inclusions, firm, breaks in conchoidal blocks.

5 Coal, black, hard, dull, bony.

6 Shale, carbonaceous, medium-gray (N5) to grayish-black (N2), firm with transitions to claystone, medium- to dark-gray, locally carbonaceous, silty to sandy, soft to firm.

7 Claystone, light-olive-gray (5Y6/1) with dark-gray (N3) to black (N1) coaly inclusions and light-brown (5YR5/6) to moderate-brown (5YR3/4)-oxidation staining, slightly sandy, soft, with few inches of shale, grayish-purple (5P4/2), bounding top and basal portions.

8 Sand, clayey, light-olive-gray (5Y6/1), medium-grained, soft, loose.

9 Claystone, sandy, light-olive-gray (5Y6/1), soft.

10 Sandstone, light-olive-gray (5Y6/1) with medium-dark-gray (N4) carbonaceous plant fragments and films, firm, clayey, with interbedded claystone, sandy, medium-gray (N5), local iron-oxide staining.

11 Sandstone, light-olive-gray (5Y6/1) predominant (but "salt and pepper"), coarse-grained, subangular to subrounded grains, locally iron-stained (limonitic) bands, friable, soft; thin (4 in.) layer of claystone, light-gray (N7), silty, soft in center.

12 Claystone, sandy, medium-olive-gray (5Y5/1) and dark-yellowish-brown (10YR4/2) streaked, and black (N1) threadlike coal stringers and fragments, soft; grades to claystone, medium-gray (N5) to moderate-yellowish-brown (10YR5/4) at base with stringers of coalified wood.

13 Claystone, pale-yellowish-orange (10YR8/6) to yellowish-gray (5Y7/2) with light-brown (5YR5/6)-weathering streaks, firm.

14 Sandstone, yellowish-gray (5Y7/2) with local dark-yellowish-orange (10YR6/6) mottling, medium-grained, friable, firm.

15 Claystone, very sandy, light-olive-gray (5Y6/1) with fine grayish-black (N2) and light-brown (5YR5/6) inclusions, soft.

16 Claystone, olive-black (5Y2/1) with grayish-black (N2) coaly inclusions, firm.

17 Claystone, sandy, grayish-yellow (5Y8/4) to yellowish-gray (5Y7/2), soft; sandstone, light (N7)- to medium-gray (N5), medium-grained, friable, soft, with abundant limonite staining, and weathered loose sand, medium- to coarse-grained with iron-oxide staining.

18 Claystone, sandy, light-olive-gray (5Y6/1), firm, with a thin (approximately 0.5 in.) coal stringer along top.

19 Sandstone, yellowish-gray (5Y7/2), medium- to coarse-grained, friable, soft to firm.

20 Claystone, olive-gray (5Y4/1), slightly sandy, soft to firm.

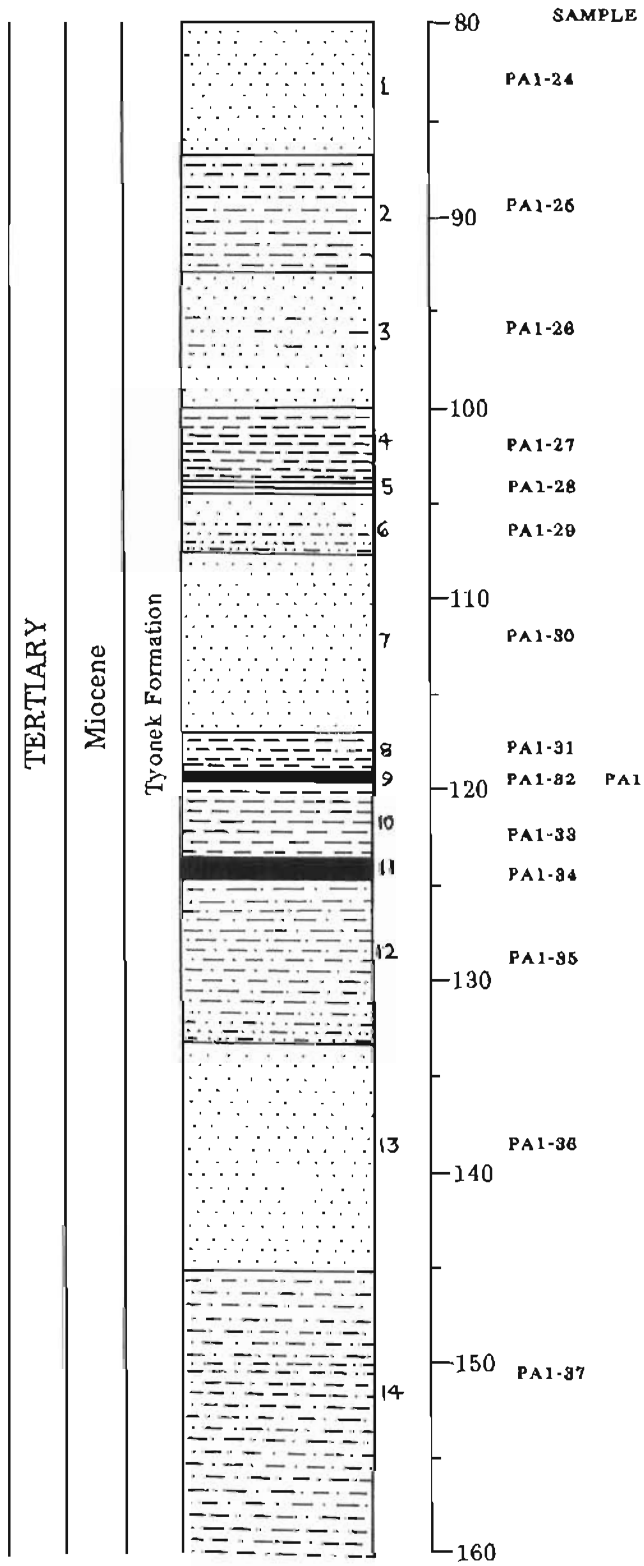
21 Sandstone, yellowish-gray (5Y8/1) with grayish-black (N2) inclusions ("salt and pepper"), medium-grained, soft, and claystone, sandy, firm.

22 Claystone, light-olive-gray (5Y6/1), firm, locally silty to slightly sandy with common hematitic surface staining.

23 Claystone and shale, interbanded, carbonaceous, dark-gray (N3) to olive-black (5Y2/1), firm.

PETERSVILLE AREA SEAMS
SITE PA1
Sheet 2 of 3

LITHOLOGIC DESCRIPTION



1 Sandstone and weathered loose sand, yellowish-gray (5Y7/2) with pale-yellowish-orange (10YR8/6) mottling, medium-grained, with disseminated black organic matter; grades to coarse-grained, loose, dark-yellowish-orange (10YR6/6), sand at base.

2 Claystone, olive-gray (5Y4/1), slightly sandy, firm with abundant limonite and hematite staining.

3 Sandstone, light-olive-gray (5Y6/1) with dark-yellowish-orange (10YR6/6)-weathering stains, medium-grained, locally slightly clayey, friable.

4 Claystone, light-olive-gray (5Y6/1) to medium-olive-gray (5Y5/1), slightly silty, firm.

5 Shale, carbonaceous, medium-gray (N5) to grayish-black (N2), fissile, firm.

6 Sandstone, clayey, light-olive-gray (5Y6/1) with light-brown (5YR5/6) mottling, abundant disseminated black organic matter and muscovite.

7 Sand, yellowish-gray (5Y7/2), medium-grained, soft, loose with abundant limonite staining.

8 Claystone, light-gray (N7), slightly sandy, soft.

9 Coal, black, firm, dull, platy.

10 Claystone, light-gray (N7), slightly silty, soft.

11 Coal, black, dull, hard, bony.

12 Claystone, sandy, light-gray (N7) with black (N1) coaly inclusions and local pale-yellowish-orange (10YR8/6) mottling, and soft, at top; grades to sand, medium-gray (N5), fine-grained, clayey, loose, soft toward basal portion.

13 Sand, grayish-orange (10YR7/4) and light-olive-gray (5Y6/1), medium-grained, soft with abundant limonite staining and disseminated black organic matter.

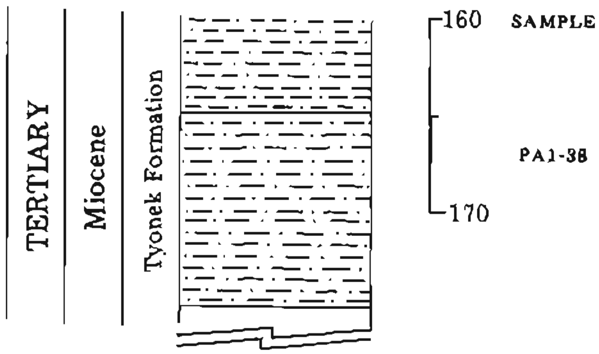
14 Claystone, medium-olive-gray (5Y5/1), slightly sandy to sandy, firm-soft.

*Petrographic sample

PETERSVILLE AREA SEAMS
SITE PA1

Sheet 3 of 3

LITHOLOGIC DESCRIPTION

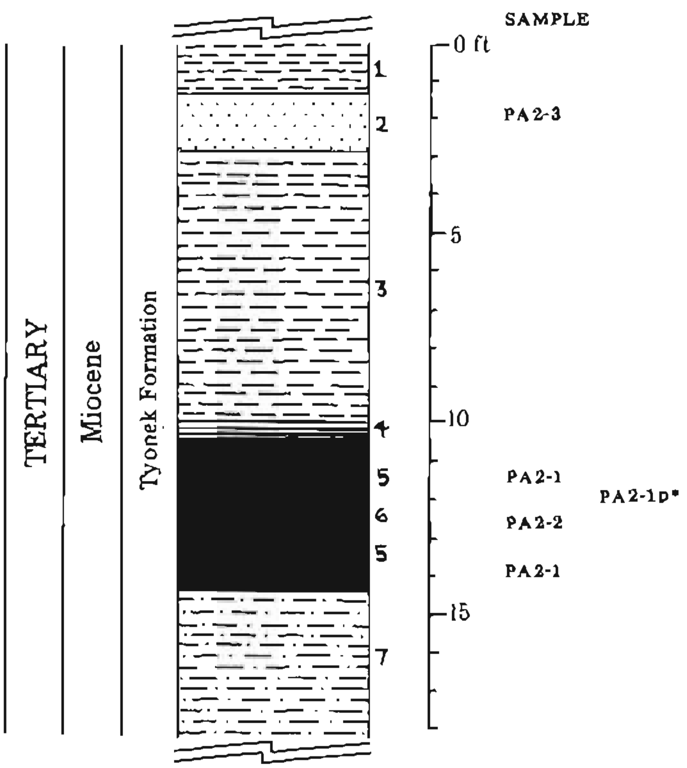


Claystone, sandy, light-gray (N7), firm.

Section discontinued at Short Creek level.

PETERSVILLE AREA SEAM
SITE PA2

LITHOLOGIC DESCRIPTION



1 Claystone, medium-gray (N5), firm.

2 Graywacke, predominantly olive-gray (5Y4/1) with light-olive-gray (5Y6/1) inclusions, carbonaceous, feldspathic; stands in relief within softer claystone unit.

3 Claystone, medium-gray (N5), slightly carbonaceous and silty, firm.

4 Shale, carbonaceous, black (N1), fissile, firm.

5 Coal, black, dull, hard, blocky in center section, woody toward top and basal portions.

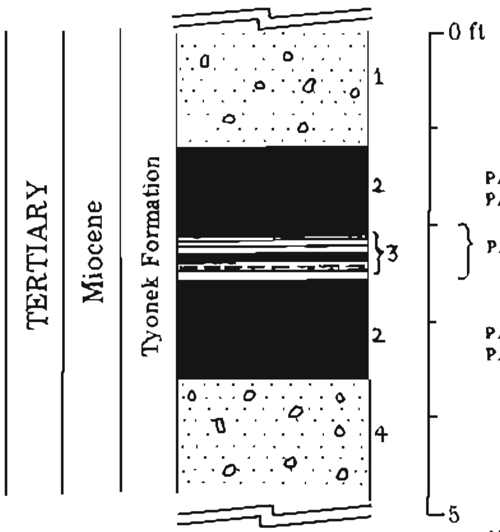
6 Claystone (possibly volcanic ash), medium-light-gray (N6) with grayish-black (N2) coaly inclusions and dark-yellowish-orange (10YR6/6) mottling, firm.

SEATROCK (underclay)

7 Claystone, sandy, medium-gray (N5), firm, locally limonite-stained.

*Petrographic sample

PETERSVILLE AREA SEAM
SITE PA3



SAMPLE

PA3-1
PA3-1p*

PA3-2

PA3-3
PA3-3p*

*Petrographic sample

LITHOLOGIC DESCRIPTION

1 ROOF
Sandstone, pebbly (quartz/chert), moderate-brownish-gray (5YR6/1), coarse-grained, granular, friable.

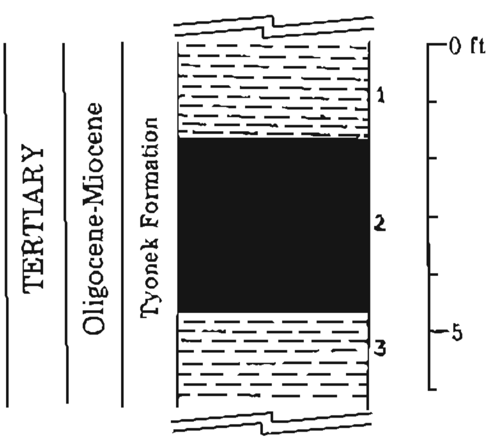
2 Coal, brownish-black, dull, woody, firm.

3 Parting, shale, carbonaceous, olive-black (5Y2/1) with grayish-black (N2) coaly inclusions and moderate-brown (5YR4/4)-weathering stains, fissile, firm, and claystone, dark-gray (N3), carbonaceous, soft, and smut, black (N1).

2 Coal, as above.

4 SEATROCK
Sandstone, pebbly, as in roof.

TALACHULITNA RIVER SEAM
SITE TR1



SAMPLE

TR1-3

TR1-1
TR1-1p*

TR1-2

*Petrographic sample

LITHOLOGIC DESCRIPTION

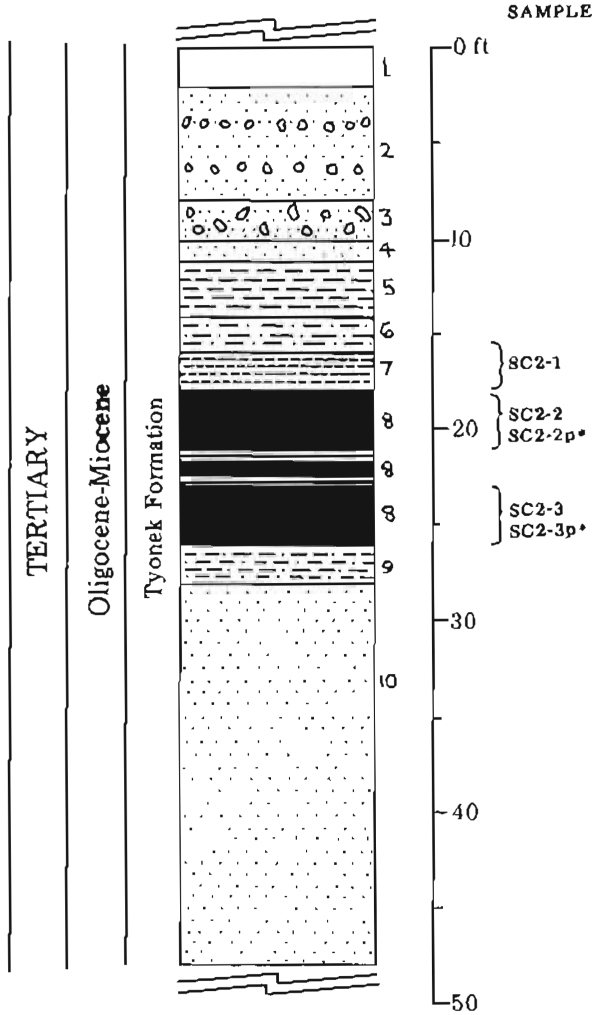
1 ROOF
Claystone, medium-olive-gray (5Y5/1), abundant limonite and hematite staining, weathers to yellow and orange shingles and conchoidal blocks, soft.

2 Coal, brownish-black, dull, woody, ashy, locally slightly contorted.

3 SEATROCK (underclay)
Claystone, light-olive-gray (5Y6/1) with local light-brown (5YR5/6) mottling and staining.

Section discontinued at water level. Metamorphosed JK greenstone faulted and juxtaposed against coal approximately 100 ft upstream.

SATURDAY CREEK SEAM
SITE SC2



*Petrographic sample

LITHOLOGIC DESCRIPTION

1 Surficial cover, brown sandy loam.

2 Sandstone, medium-gray, medium-grained, with yellow-iron-oxide staining locally; interbands of quartz-pebble conglomerate (pebbles to 2 in. diameter) up to 0.5 ft thick.

3 Conglomerate, monomictic, quartz-pebble, hard, well-cemented.

4 Sandstone, medium-yellowish-gray, medium-grained, hard, with surficial iron-oxide-weathering stains.

5 Claystone, dark-gray, carbonaceous, firm.

6 Claystone, sandy, light-gray, firm.

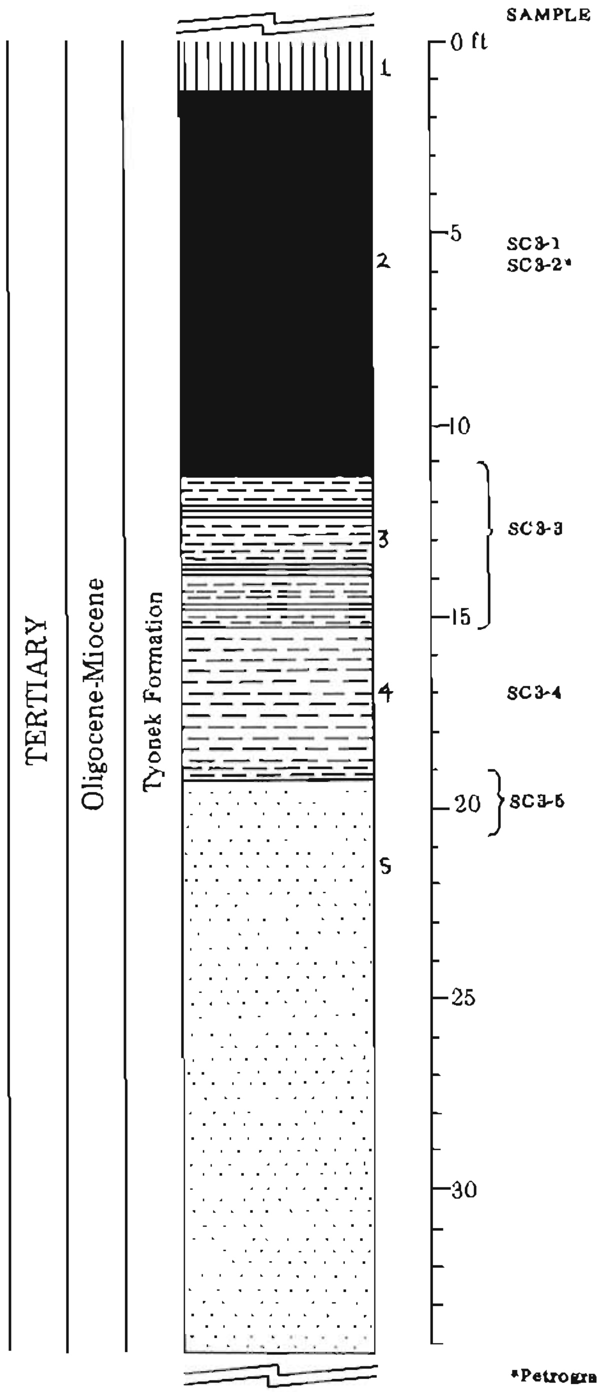
7 Claystone, medium-light-gray (N6) with black (N1) coaly inclusions and light-brown (5YR5/6)-weathering stains, firm, breaks conchoidal fracture.

8 Coal, black, blocky, hard; middle has black, carbonaceous shale, partings.

SEATROCK (underclay)
9 Claystone, light-gray, slightly sandy, firm.

10 Sandstone, medium-yellowish-gray, medium-grained, very hard, surficial iron-oxide-weathering stains.

SATURDAY CREEK SEAM
SITE SC3



*Petrographic sample

LITHOLOGIC DESCRIPTION

1 Roof not exposed; covered interval.

2 Coal, black, dull, platy, bony, highly weathered on surface.

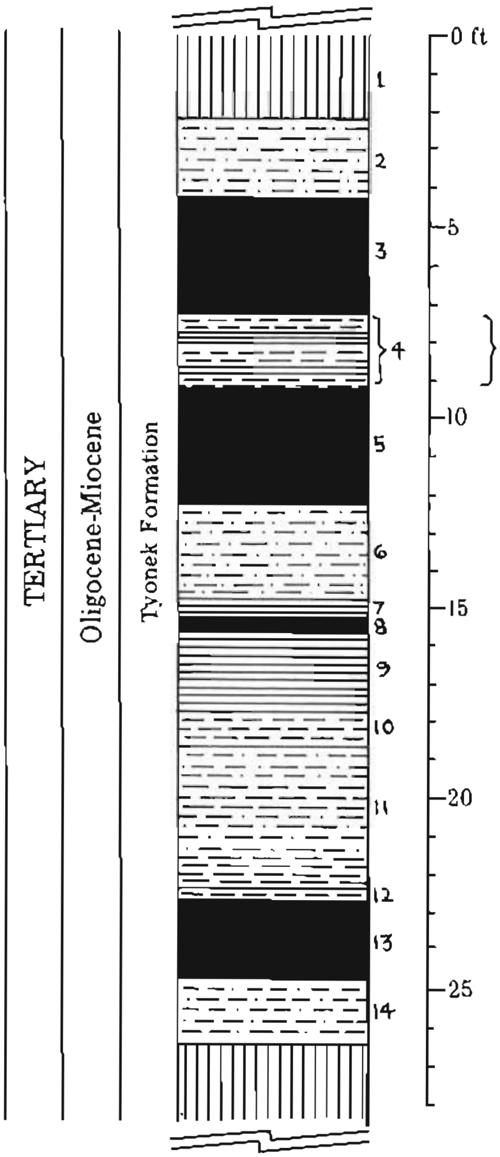
SEATROCK

3 Claystone, brownish-gray (5YR4/1), locally carbonaceous, firm to soft, with light-brown (5YR5/6) iron-oxide staining; interbedded with shale, carbonaceous, black (N1), fissile, firm.

4 Claystone, light-gray (N7) to light-olive-gray (5Y6/1), locally slightly carbonaceous, firm to soft, breaks with conchoidal fracture.

5 Sandstone and sand, yellowish-gray (5Y7/2) to light-olive-gray (5Y6/1), medium- to coarse-grained, angular to subrounded grains, disseminated fine black organic matter and muscovite, but predominantly quartz sand, friable to loose.

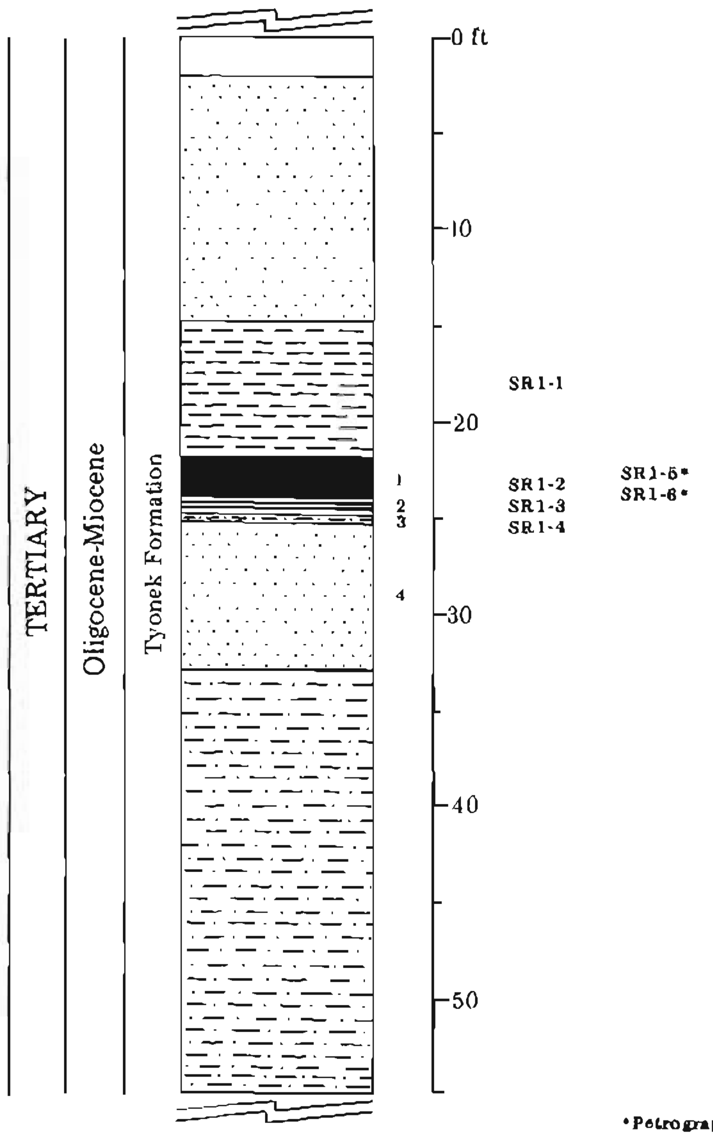
SATURDAY CREEK SEAMS
SITE SC4



Unit	Sample	Petrographic sample	Lithologic description
1			Covered interval for 30 ft to top of ridge.
2	SC4-1	SC4-2a*	Claystone, sandy, olive-gray (5Y4/1) with dark-yellowish-orange (10YR6/6)- to light-brown (5YR5/6)-weathering mottles.
3	SC4-2	SC4-2b*	Coal, black, hard, bright, blocky.
4	SC4-3		Claystone, grayish-black (N2), carbonaceous, firm, rooted, and shale, carbonaceous, dark-gray (N3) to black (N1), fissile and firm, intercalated.
5	SC4-4	SC4-4a*, SC4-4b*	Coal, black, bright, hard, platy; becomes bony toward basal portion.
6	SC4-5		Claystone, sandy, light-olive-gray (5Y6/1) with black (N1) coaly inclusions and local dark-yellowish-orange (10YR6/6) weather banding, firm.
7	SC4-6		Shale, carbonaceous, grayish-black (N2), fissile, weathered and soft.
8	SC4-7	SC4-7p*	Coal, black, very hard, breaks conchoidal fracture, possibly cannel coal.
9	SC4-8		Shale, carbonaceous, medium-dark-gray (N4) to black (N1), fissile, firm.
10	SC4-9		Claystone, light-olive-gray (5Y6/1), with disseminated black organic matter, rooted, hematite-stained, soft.
11	SC4-10		Claystone, light-olive-gray (5Y6/1) with medium-dark gray (N4) coaly inclusions and local dark-yellowish-orange (10YR6/6) mottling, slightly sandy, breaks with conchoidal fracture.
12	SC4-11		Claystone, medium-olive-gray (5Y5/1) with black (N1) coaly inclusions and local dark-yellowish-orange (10YR6/6) mottling, firm.
13	SC4-12	SC4-12p*	Coal, black, dull, hard, platy, bony.
14	SC4-13		Claystone, olive-gray (5Y4/1) with dark-gray (N3) coaly inclusions, slightly sandy, firm, locally limonite-stained.
			Covered interval for 30 ft down to creek level.

*Petrographic sample

SKWENTNA RIVER SEAM
SITE SR1



LITHOLOGIC DESCRIPTION

Surficial cover; light-brown sandy loam.

Sand, light-yellow to brownish-yellow, medium-grained, loose, soft, weathered with iron-oxide staining.

Claystone, medium-olive gray (5Y5/1), slightly carbonaceous, firm, breaks with conchoidal fracture.

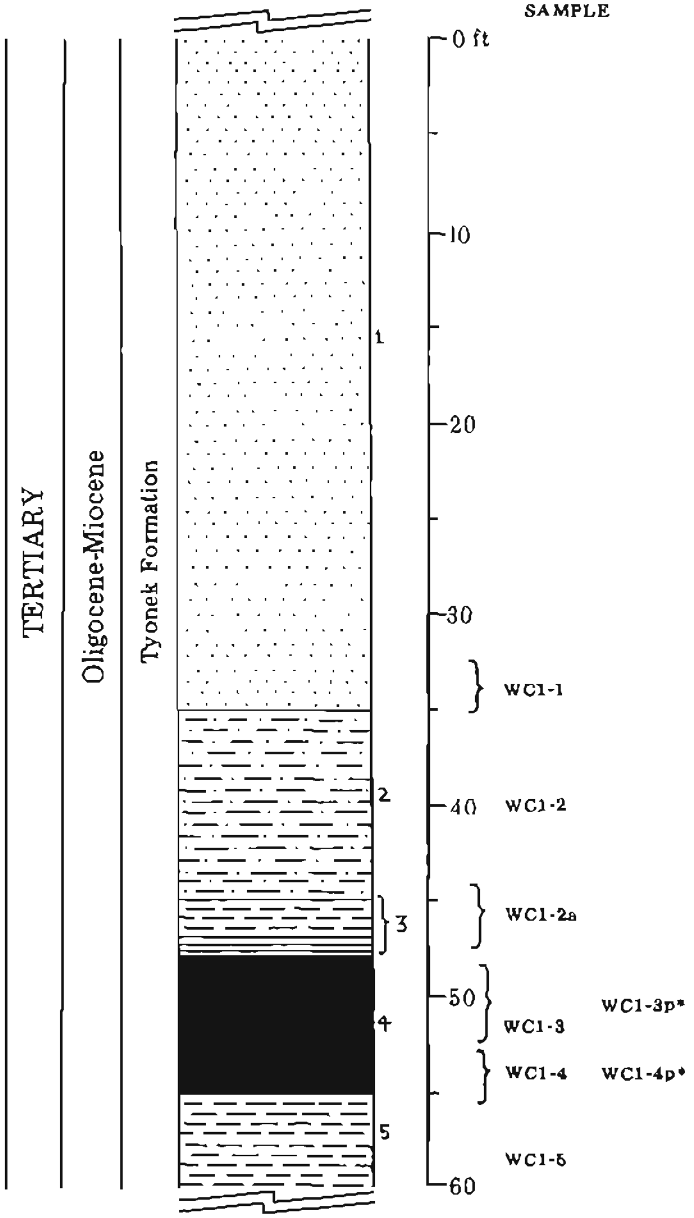
1 Coal, black, dull, thinly plated, bony.
2 Shale, carbonaceous, dark-gray (N3) to grayish-black (N2), fissile, highly weathered, soft.
3 Claystone, sandy, light-olive-gray (5Y6/1) with olive-gray (5Y4/1) streaks, carbonaceous, firm.
4 Sand, yellow to orange, medium-grained, highly weathered with iron-oxide staining, disseminated black organic matter, micaceous, loose.

Claystone, sandy, dark-gray, carbonaceous, soft-firm.

*Petrographic sample

WOLVERINE CREEK SEAM
SITE WC1

LITHOLOGIC DESCRIPTION



*Petrographic sample

1 Sandstone, light-olive-gray (5Y6/1) speckled ("salt and pepper") with white (N9) and medium-light-gray (N6), coarse-grained, angular to subangular grains, friable, soft-firm.

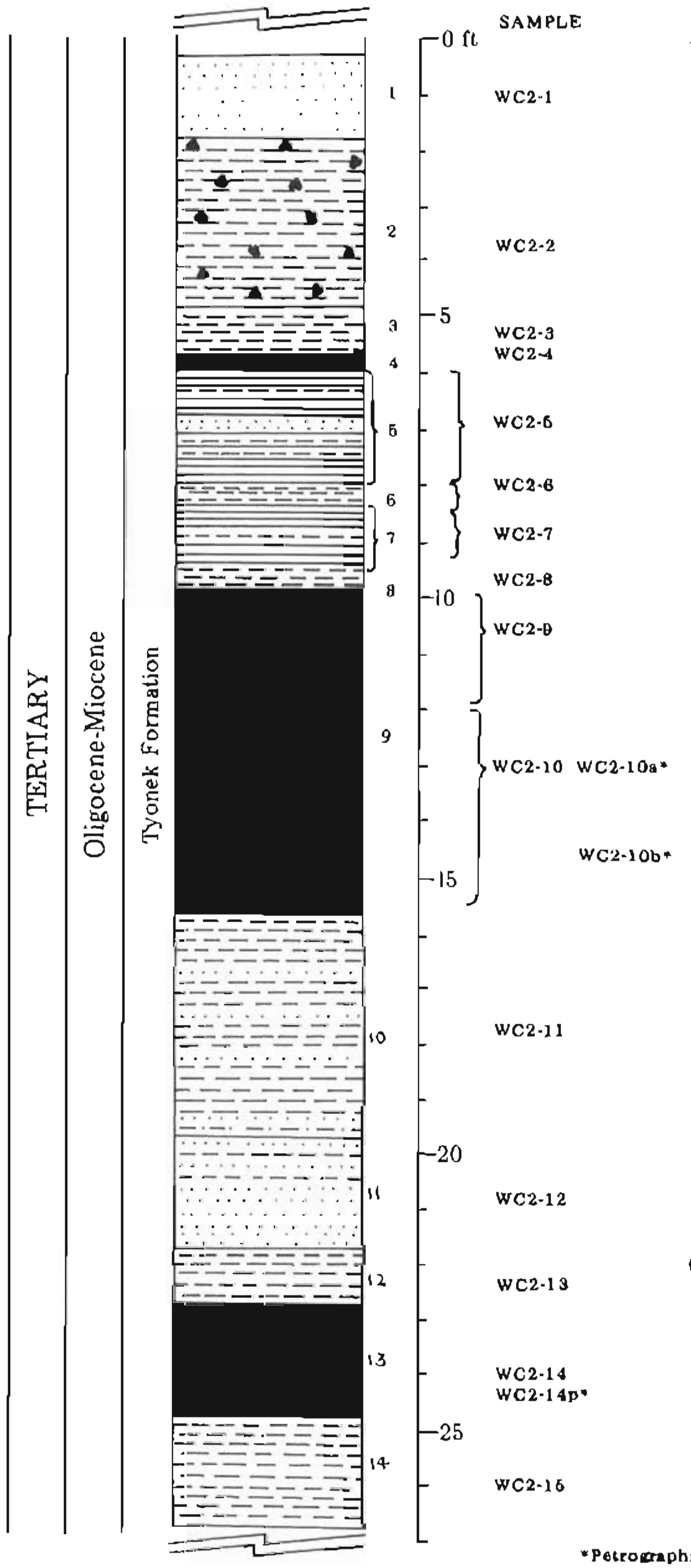
2 Claystone, sandy, medium-light-gray (N6) streaked medium-dark-gray (N4), soft, breaks in blocks, abundant limonite stains along surfaces and joints.

3 Claystone, grayish-black (N2) with olive-gray (5Y4/1) streaks, carbonaceous, soft, and shale, carbonaceous, black (N1), fissile, soft.

4 Coal, black, predominantly bright, hard, blocky; basal 3 ft highly weathered and limonite-stained.

5 SEATROCK (underclay)
Claystone, medium-gray (N5) with abundant dark-yellowish-orange (10YR6/6) staining, soft.

WOLVERINE CREEK SEAM
SITE WC2



LITHOLOGIC DESCRIPTION

1 Sandstone, light-gray (N7) with dark-yellowish-orange (10YR6//) mottles, coarse-grained, locally clayey and slightly carbonaceous, "salt and pepper."

2 Claystone, olive-gray (5Y4/1), soft to firm, breaks in blocky masses, abundant iron-rich (limonite rim, hematite core) septarian nodules.

3 Claystone, brownish-gray (5YR4/1) with grayish-black (N2) streaks and inclusions, soft.

4 Coal stringer, black, hard, platy to slightly blocky.

5 Shale, carbonaceous, olive-black (5Y2/1) with dark-yellowish-orange (10YR6/6) mottles, fissile, firm, interlayered with claystone, brownish-gray (5YR4/1), locally silty, abundant limonite stains along surfaces and bedding planes; central (0.5 ft) layer of sandstone, grayish-brown (5YR3/2), medium-grained, hard, iron-stained.

6 Claystone, olive-gray (5Y4/1) with light-brown (5YR5/6) mottles, locally slightly carbonaceous and iron-stained, soft to firm.

7 Shale, carbonaceous, dark-gray (N3) with light-brown (5YR5/6)-weathering stains, fissile, soft to firm, interbanded with claystone, dark-gray (N3), carbonaceous, soft.

8 Claystone, dark-yellowish-brown (10YR4/2), slightly silty and carbonaceous, soft.

9 Coal, black, dull, firm to hard, blocky, weathered locally with abundant iron-oxide staining.

10 Claystone, very sandy, light-olive-gray (5Y6/1), soft, locally with abundant iron-oxide staining; interbanded with sand lenses, light-gray (N7), medium-grained, micaceous, friable, soft.

11 Sandstone, light-olive-gray (5Y6/1) streaked olive-gray, medium-grained, friable, soft, abundant limonite staining; thin (approximately 1 in. thick) interbands of claystone, medium gray (N5), silty, soft, toward top.

12 Claystone, light-gray (N7), breaks with blocky, conchoidal fracture, abundant iron-oxide staining.

13 Coal, black, dull, hard, blocky, locally weathered with abundant limonite staining.

14 Claystone, light-olive-gray (5Y6/1), silty, soft.

*Petrographic sample

APPENDIX D
Calculations for Statistical Markov Chain Analysis

APPENDIX D

Calculations for statistical Markov-chain analysis (after Gingerich, 1969). Refer to text for discussion of results.

A. Frequency of occurrence of five rock types:

Shale (SH)	5		
Coal (CO)	7		beds
Claystone (CL)	12	=	f_i
Sandstone (SS)	8		
Conglomerate (CG)	4		
Total =	36		

B. Independent-trials matrix:

	SH	CO	CL	SS	CG	
SH	0.00	0.22	0.39	0.26	0.13	
CO	0.17	0.00	0.41	0.28	0.14	
CL	0.21	0.29	0.00	0.33	0.17	= e_{ij}
SS	0.18	0.25	0.43	0.00	0.14	
CG	0.16	0.22	0.38	0.25	0.00	

C. Transition count matrix:

	SH	CO	CL	SS	CG	
SH	0	0	3	0	2	
CO	4	0	2	0	0	
CL	1	6	0	4	1	= f_{ij}
SS	0	1	6	0	0	
CG	0	0	0	4	0	

D. Transition probability matrix:

	SH	CO	CL	SS	CG	
SH	0.00	0.00	0.60	0.00	0.40	
CO	0.67	0.00	0.33	0.00	0.00	
CL	0.08	0.50	0.00	0.33	0.08	= p_{ij}
SS	0.00	0.14	0.86	0.00	0.00	
CG	0.00	0.00	0.00	1.00	0.00	

E. Calculation of χ^2 statistic

$$\chi\, v^2 = \sum_{ij} (f_{ij} - f_i e_{ij})^2 / f_i e_{ij}$$

The number of positive elements in e_{ij} is 20.
The rank of e_{ij} is 5. The rank of a matrix is the maximum number of independent row vectors or column vectors. The rank is determined by converting the matrix to row-echelon form and finding the number of non-zero rows or columns (Hawkins, personal commun., 1982).

Echelon form of matrix:

	SH	CO	CL	SS	CG
SH	1	0	2.59	1.65	0.82
CO	0	1	1.77	1.18	0.59
CL	0	0	1	0.34	0.16
SS	0	0	0	1	0.18
CG	0	0	0	0	1

The degrees of freedom are 15. This is determined by subtracting the rank of e_{ij} from the total number of positive entries:

$v = 20 - 5 = 15$

Solving for the equation yields an χ^2 of 35.9.

F. Difference matrix:

	SH	CO	CL	SS	CG
SH	0.00	-0.22	0.21	-0.26	0.27
CO	0.50	0.00	-0.08	-0.28	-0.14
CL	-0.13	0.21	0.00	0.00	-0.09
SS	-0.18	-0.11	0.43	0.00	-0.14
CG	-0.16	-0.22	-0.38	0.75	0.00

$= p_{ij} - e_{ij}$

The positive elements in the difference matrix represent those transitions that have a higher than random probability of occurring.

APPENDIX E
Overburden-characterization Data

Table E-1. *Overburden procedures and references.*

Parameter	Unit	Procedure	Reference
Paste pH	pH	Electrode	USDA (1954), p. 102; Sobek and others, 1978, p. 45-47.
Electrical conductivity	mmhos/cm	Conductivity bridge	USDA (1954), p. 89.
Saturation percentage	%	Dried to 105°C, weight loss	USDA (1954), p. 10.
Water-soluble cations (Ca, Mg, Na)	meq/l	Vacuum extraction, atomic absorption	USDA (1954), p. 84.
SAR[a]	(ratio)	Calculation from water-soluble cations	USDA (1954), p. 26, p. 72-75.
ESP[b]	%	Extraction	ASA (1965), part 2, p. 1033-1034.
Boron	ppm	Hot-water soluble, Carmine method	ASA (1965), part 2, p. 1062-1063.
Selenium	ppm	Hot-water extraction, hydride, atomic absorption	ASA (1965), part 2, p. 1122.
Acid-base potential	tons $CaCO_3$ equivalent/1,000 tons soil material	Total sulfur, % $CaCO_3$, titration and turbidimetric	Sobek and others, 1978, p. 47-55.
Lime	%	$CaCO_3$ equivalent from acid neutralization	USDA (1954), p. 105.
Sulfur	%	Leco method	Leco (1975), p. 1-51; Sobek and others, 1978, p. 51-55.

[a]Sodium adsorption ratio.
[b]Exchangeable sodium percentage.

Table E-2. *Physical and chemical data*

Sample	pH (paste)	EC[a] (mmhos/cm)	Sat[b] (%)	Saturation extract cations (meq/l) Ca	Mg	Na	SAR[d]	ESP[e]	Particle-size analysis hydrometer (%) Sand	Silt	Clay	Texture[f]	OM[c] (%)	Lime (%)	Total boron (ppm)	Se (ppm)
BR1-2	6.6	0.2	47.1	1.4	1.0	0.6	0.5	2.8	36	25	39	CL	2.67	9.5	54.5	<0.01
BR1-3	6.9	0.4	36.1	2.8	1.8	0.6	0.4	3.8	29	55	16	SiL	1.07	9.8	100.0	<0.01
BR1-5	6.4	0.6	42.9	4.2	2.9	0.6	0.3	35.0	49	32	19	L	6.54	10.0	60.8	<0.01
BR1-6	6.3	0.3	48.0	2.1	1.2	0.7	0.5	5.5	7	77	16	SiL	1.91	9.9	1.3	<0.01
BR1-7	6.1	0.9	42.8	6.3	4.4	0.8	0.3	3.0	60	21	19	SL	5.31	9.5	39.5	<0.01
BR1-9	6.9	0.2	46.3	1.4	0.7	0.6	0.6	8.0	8	74	18	SiL	1.97	9.7	36.8	<0.01
BR1-10	6.9	0 3	34.7	2.0	1.2	0.6	0.5	8.4	46	45	9	L	0.96	9.8	16.7	<0.01
BR1-11	6.8	0.2	42.6	1.7	1.0	0.6	0.5	3.2	51	38	11	L	2.82	9.7	6.3	<0.01
BR1-13	6.5	0.3	46.0	1.6	1.2	0.6	0.5	5.1	11	55	34	SiCL	3.16	10.0	59.3	<0.01
BR1-14	6.4	0.3	37.3	1.4	0.9	0.6	0.6	12.7	56	35	9	L	1.20	9.8	25.5	<0.01
BR1-16	6.7	0.4	44.0	2.6	2.2	0 7	0.5	3.8	10	45	45	SiC	2.27	9.9	15.7	<0.01

[a]Electrical conductivity.
[b]Saturation percentage.
[c]Organic matter.
[d]Sodium adsorption ratio.
[e]Exchangeable sodium percentage.
[f]C - Clay
L - Loam
S - Sand
Si - Silt.
[g]Neutralization potential.
[h]Potential acidity (positive values indicate excess $CaCO_3$—basic overburden material).

Table E-3. *Physical and chemical data on*

Sample	pH (paste)	EC[a] (mmhos/cm)	Sat[b] (%)	Saturation extract cations (meq/l) Ca	Mg	Na	SAR[c]	ESP[d]	Particle-size analysis hydrometer (%) Sand	Silt	Clay	Texture[e]	OM[f] (%)	Lime (%)	Total boron (ppm)	Se (ppm)
FM1-1	4.1	0.2	85.3	1.1	0.9	0.4	0 4	0.7	89	4	7	S-LS	9.46	10.0	11.2	<0.01
FM1-3	4.8	0.1	49.5	0.6	0.4	0.4	0.6	2.1	15	53	32	SiCL	6.10	9.8	62.8	<0.01
FM1-5	5.1	0.1	38.6	0.5	0.3	0.5	0.8	3.8	11	64	25	SiL	1.59	9.9	7.4	<0.01
FM1-6	4.2	0.3	90.4	2.5	1.2	0.4	0.3	0.7	96	0	4	S	8.63	9.0	38.9	<0.01
FM1-8	4.7	0.1	43.6	0.6	0.3	0.4	0.6	2.4	10	54	36	SiCL	2.32	10.0	16.6	<0.01
FM1-9	4.6	0.1	69.6	1.1	0.5	0.4	0.4	1.1	46	10	44	SC-C	11.89	9.3	21.1	<0.01
FM1-11	5.1	0.1	45.8	0.2	<0.1	0.6	2.2	5.1	18	60	22	SiL	1.27	9.9	43.7	<0.01
FM1-12	4.8	0.3	83.2	2.2	1.2	0.4	0 3	1.0	86	2	12	LS	9 56	8.3	36.1	<0.01
FM1-14	7.2	0.4	43.0	3.1	1.6	0.5	0.3	6.7	38	49	13	L	1.94	10.1	21.3	0.05

[a]Electrical conductivity.
[b]Saturation percentage.
[c]Sodium adsorption ratio.
[d]Exchangeable sodium percentage.
[e]C - Clay
L - Loam
S - Sand
Si - Silt.
[f]Organic matter.
[g]Cation-exchange capacity.
[h]Neutralization potential.
[i]Potential acidity (positive values indicate excess $CaCO_3$—basic overburden material).

on overburden, Beluga River samples.

Extractable nutrients (ppm)			Ammonium acetate extractable cations (meq/100 g)										Tons $CaCO_3$/1,000 tons	
NO_3	P	K	Ca	Mg	Na	K	CEC (meq/100 g)	Base saturation (%)	SO_4-S (%)	Pyritic sulfur (%)	Total sulfur (%)	Acid potential meq H^+/100 g)	NP[g]	PA[h]
2.4	29.82	147.7	11.3	6.3	0.7	0.2	24.4	75.8	<0.1	0.01	0.04	2.5	14.69	13.44
3.8	17.51	186.6	9.5	4.2	0.6	0.3	16.5	94.2	<0.1	0.02	0.04	2.5	15.97	14.72
4.7	10.35	198.8	9.3	3.2	0.7	0.3	2.0	100.0	<0.1	0.09	0.10	6.3	125.69	122.54
10.0	8.56	172.6	5.6	1.9	0.6	0.3	10.8	77.8	<0.1	0.02	0.04	1.3	23.09	22.44
3.8	23.85	280.4	16.6	4.2	0.7	0.7	23.0	92.2	<0.1	<0.01	0.06	3.8	10.03	8.13
2.4	13.18	131.0	9.8	3.0	0.7	0.3	8.8	100.0	<0.1	0.02	0.02	1.3	27.17	26.52
5.3	12.74	140.7	11.3	4.4	0.7	0.3	8.3	100.0	<0.1	0.01	0.01	0.6	12.13	11.83
2.4	16.76	215.8	11.8	5.6	0.7	0.5	21.9	84.9	<0.1	0.01	0.02	1.3	8.05	7.10
9.1	16.32	195.0	9.2	3.9	0.7	0.6	13.6	100.0	<0.1	0.01	0.01	0.6	31.02	30.72
6.6	11.32	98.6	6.4	2.0	0.7	0.2	6.5	100.0	<0.1	0.01	0.01	0.6	13.64	13.34
13.8	19.60	251.7	11.1	5.7	0.7	0.6	18.3	98.9	<0.1	0.01	0.01	0.0	34.40	34.40

overburden, Fairview Mountain samples.

Extractable nutrients (ppm)			Ammonium acetate extractable cations (meq/100 g)										Tons $CaCO_3$/1,000 tons	
NO_3	P	K	Ca	Mg	Na	K	CEC[a] (meq/100 g)	Base saturation (%)	SO_4-S (%)	Pyritic sulfur (%)	Total sulfur (%)	Acid potential (meq H^+/100 g)	NP[h]	PA[i]
3.1	18.78	60.4	9.8	4.7	0.6	<0.1	88.4	17.0	<0.1	0.06	0.30	18.8	3.85	-5.65
3.3	14.30	113.7	10.1	6.4	0.6	<0.1	29.0	55.2	<0.1	0.02	0.06	3.8	7.23	5.33
3.0	7.29	137.4	7.9	4.4	0.6	0.2	15.6	84.0	<0.1	0.01	0.02	0.6	7.70	7.40
3.4	15.80	47.6	10.2	2.9	0.6	<0.1	81.5	16.7	<0.1	0.01	0.48	30.0	9.56	-5.44
3.1	14.90	144.1	9.8	4.0	0.6	0.2	24.6	59.3	<0.1	0.02	0.02	1.3	5.01	4.36
3.2	11.25	102.2	18.7	5.6	0.6	<0.1	52.3	47.4	<0.1	0.01	0.14	8.8	8.51	4.11
2.9	14.68	134.8	7.2	2.7	0.6	0.1	11.7	90.6	<0.1	0.01	0.01	0.6	6.30	6.00
3.3	11.62	61.8	13.4	6.0	0.6	<0.1	57.2	34.8	<0.1	0.04	0.32	20.0	18.07	8.07
3.1	8.19	70.6	7.2	2.5	0.6	<0.1	9.0	100.0	<0.1	0.04	0.04	1.9	26.47	25.52

Table E-4. *Chemical data on overburden, Canyon Creek site.*

Sample	pH (paste)	Electrical conductivity (mmhos/cm)	Saturation (%)	Extractable nutrients (ppm) NO_3	P	K	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[a]
CnC8-1	5.3	0.1	43.6	3.0	19.52	93.7	0.04	2.5	16.79	15.54
CnC8-3	4.7	0.4	62.3	4.6	10.13	105.0	0.26	16.3	10.84	2.69
CnC8-4	5.1	0.2	47.8	4.7	10.87	82.2	0.02	1.3	16.21	15.56

[a]Positive values indicate excess $CaCO_3$ (basic overburden material).

Table E-5. *Chemical data on overburden, Johnson Creek samples.*

Sample	pH (paste)	Electrical conductivity (mmhos/cm)	Saturation (%)	Extractable nutrients (ppm) NO_3	P	K	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[a]
JC3-2	7.2	0.2	61.9	5.1	21.54	113.2	0.09	5.6	18.42	15.62
JC3-3	6.3	0.1	50.3	3.6	21.17	134.3	0.02	1.3	16.67	16.02
JC3-4	6.7	0.2	68.2	4.1	38.54	153.2	0.15	9.4	8.28	3.58
JC3-6	6.7	0.2	47.2	2.2	17.81	223.0	0.02	1.3	14.58	13.93

[a]Positive values indicate excess $CaCO_3$ (basic overburden material).

Table E-6. *Chemical data on overburden, Wolverine Creek samples.*

Sample	pH (paste)	Electrical conductivity (mmhos/cm)	Saturation (%)	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[a]
WC2-1	6.4	0.3	35.8	0.02	1.3	19.59	18.94
WC2-2	6.5	0.5	58.6	0.03	1.9	36.73	35.78
WC2-3	5.9	0.5	72.8	0.20	12.5	33.00	26.75
WC2-5	5.7	0.6	61.0	0.16	10.0	45.47	40.47
WC2-6	5.7	0.2	65.1	0.05	3.1	26.82	25.28
WC2-7	5.6	0.7	81.9	0.42	26.3	32.30	19.15
WC2-8	6.0	0.2	60.9	0.07	4.4	24.60	22.40
WC2-11	6.3	0.1	47.5	0.01	0.6	16.56	16.26
WC2-12	6.8	0.1	42.0	0.01	0.6	15.39	15.09
WC2-13	5.5	0.1	53.1	0.00	0.0	26.00	26.00
WC2-15	5.7	0.2	50.7	0.01	0.6	20.99	26.69

[a]Positive values indicate excess $CaCO_3$ (basic overburden material).

Table E-7. *Physical and chemical data on overburden, Peters Hills area samples.*

Sample	pH (paste)	EC[a] (mmhos/cm)	Sat[b] (%)	Particle-size-analysis hydrometer (%) Sand	Silt	Clay	Texture[c]	Ammonium acetate extractable cations (meq/100 g) Ca	Mg	Na	K	CEC[d] (meq/100 g)	Base sat. (%)	ESP[e]	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[f]
PA1-1	5.9	0.1	24.6	85	8	7	LS	2.5	0.3	0.7	<0.1	1.3	100.0	53.8	0.00	0.0	7.00	7.00
PA1-2	5.7	0.1	42 0	29	64	7	SiL	7.0	1.7	0.7	0.2	11 9	80.7	5.9	0.00	0.0	15.97	15 97
PA1-3	5.2	0.2	51.4	11	77	12	SiL	3 5	0.7	0.6	0.1	8.4	58.3	7.1	0.01	0.6	20.64	20.34
PA1-4	6 1	0.3	49.4	26	26	48	C	11.0	2.5	0.6	0.3	25.6	56.3	2.3	0.02	1.3	34.51	33.86
PA1-6	5.8	0.5	89.3	70	8	22	SCL	34.4	4.7	0 6	0.1	44.0	90.5	1.4	0.06	3.8	34.86	32.96
PA1-7	5.9	0.3	57.1	32	44	24	L	13.6	3.4	0.6	0.1	27.7	63.9	2.2	0.06	3 8	25.65	23.75
PA1-8	7.0	0.1	45.3	27	59	14	SiL	5.5	1.2	0.6	0.1	7.7	96.1	7.8	0.00	0.0	23.20	23.20
PA1-9	7.0	0.2	46.9	25	62	13	SiL	5.9	1.4	0.6	0.1	7 6	100.0	7.9	0.01	0 6	22.85	22.55
PA1-10	7.1	0.2	53.4	8	67	25	SiL	6.0	2.0	0.6	0.2	15.0	58.7	4.0	0.00	0.0	26.47	26.47
PA1-11	7.1	0.1	41.6	62	30	8	SL	4.7	1.9	39.5	0.1	7 8	100.0	506.4	0.00	0.0	17.37	17.37
PA1-12	6 8	0.1	50.3	12	72	16	SiL	9.6	3.1	4.7	0.2	17.4	100.0	27.0	0.01	0.6	23.20	22.90
PA1-13	7.1	0.2	45.7	16	63	21	SiCL	11.0	4.1	0.7	0.2	20.9	76.6	3 3	0.00	0.0	31.13	31.13
PA1-14	7.0	0.1	42.7	61	32	7	SL	7.0	1.9	0.7	0 2	9 6	100.0	7.3	0.01	0.6	15.51	15.21
PA1-15	6 9	0.2	49.5	14	73	13	SiL	9.8	2.5	0.7	0.3	15 1	88.1	4.6	0.00	0.0	21.92	21.92
PA1-16	6 8	0.4	80.5	82	5	13	LS-SL	45.4	8.1	0.7	0.2	56.4	96.5	1.2	0.28	17.5	41.86	33 11
PA1-17	7.0	0.1	38.4	58	36	6	SL	7.0	1.1	0.6	0.1	6 7	100.0	9.0	0.00	0.0	12 36	12 36
PA1-18	6 8	0.2	46 9	22	53	25	SiL	8.4	3.7	0.6	0 3	15.8	82.3	3.8	0 02	1.3	17.72	17.07
PA1-20	6 8	0.1	46.9	15	74	11	SiL	7.0	3.5	0.6	0.3	11.3	100.0	5.3	0.00	0.0	19 01	19.01
PA1-21	7.0	0.1	IS[g]	56	36	8	SL	6.3	2.1	0.6	0 1	8 9	100.0	6.7	0.00	0.0	14.34	14.34
PA1-22	6.9	0 2	52.4	12	71	17	SiL	7.5	3.1	0.6	0 3	12.3	93.5	4.9	0.00	0.0	20.06	20.06
PA1-23	6.8	0.3	75 8	71	4	25	SCL	16.3	9.0	0.6	0.3	44.9	58.4	1.3	0.16	10.0	35.68	30.68
PA1-24	7.2	0.1	37.4	83	12	5	LS	5.0	1.5	0.6	0.1	5.8	100.0	10.3	0 00	0.0	8.63	8.63
PA1-25	6 9	0.1	43.6	27	61	12	SiL	6.5	3.2	0.6	0 2	12.7	81.9	4.7	0.00	0 0	16.56	16.56
PA1-26	6.9	0.1	41 7	62	31	7	SL	3.9	1.7	0.6	0.1	6.1	100.0	9.8	0.01	0.6	13 64	13.34
PA1-27	7.0	0.2	48.2	18	53	29	SiCL	9.7	3.3	0.6	0.3	21.0	66.2	2 8	0.00	0.0	30 43	30.43
PA1-28	6.7	0 9	94.1	82	2	16	SL	41.1	6.7	0.6	0.1	50.9	95.3	1.2	0 12	7.5	55.62	51.87
PA1-29	7.1	0.2	41.1	42	34	24	L	8.1	2 6	0.6	0.1	11.9	95.8	5.0	0.01	0.6	18.66	18.36
PA1-30	7.2	0.1	35.8	84	9	7	LS	7.3	1.7	0.6	<0.1	8.1	100.0	7.4	0.01	0 6	15.74	15.44
PA1-31	6.8	0.2	53.8	6	59	35	SiCL	8.7	4.5	0 6	0.4	22.2	64.0	2.7	0.00	0.0	27 17	27.17
PA1-33	7.2	0.2	47 8	12	56	32	SiCL	8.3	2.3	0.6	0.2	12.3	92.7	4.9	0.00	0.0	12.83	12.83
PA1-35	7.1	0.1	38 8	46	41	13	L	4.2	0.6	0.6	0.1	4.7	100.0	12.8	0.00	0.0	9 56	9.56
PA1-36	7.1	0.1	29.8	82	10	8	LS	3.3	0.4	0.6	<0.1	3.9	100.0	15.4	0.01	0.6	7.93	7.63
PA1-37	7.0	0.2	47.5	16	56	28	SiCL	9.0	2.7	0.6	0.2	14.9	83.9	4.0	0.00	0.0	22.50	22.50
PA1-38	7.5	0.6	45.9	10	68	22	SiL	6.3	0 7	0.6	0 1	5 3	100.0	11.3	0.00	0.0	15.51	15 51

[a]Electrical conductivity.
[b]Saturation percentage.
[c]C - Clay
L - Loam
S - Sand
Si - Silt.
[d]Cation-exchange capacity.
[e]Exchangeable sodium percentage.
[f]Positive values indicate excess $CaCO_3$ (basic overburden material).
[g]Insufficient sample.

Table E-8. *Chemical data on overburden, Saturday Creek samples.*

Sample	pH (paste)	EC[a] (mmhos/cm)	Saturation (%)	Saturation extract cations (meq/l) Ca	Mg	Na	SAR[b]	OM[c] (%)	Lime (%)	Extractable nutrients (ppm) NO_3	P	K	SO_4-S (%)	Pyritic sulfur (%)	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[d]
SC4-1	6.0	0.1	44.7	0.1	0.2	0 5	1.3	0.82	9.9	3 3	14.68	90.2	<0.1	0.01	0.04	0.6	12.01	11.71
SC4-3	4.9	0.2	63.5	1.7	1.2	0.5	0.4	10.27	9.2	3.6	22.21	80.7	<0.1	0.03	0 20	12 5	23.90	17.65
SC4-5	5.2	0.1	38.2	0.5	0.2	0.5	0.8	2.45	10.0	3.0	37.43	70.3	<0.1	0.02	0.04	1.3	18.69	18.24
SC4-6	5.4	0.6	83.5	3.9	3.4	0.6	0.3	11.55	8.8	2.1	10.80	86.1	<0.1	0.04	0.14	8.8	38.83	34.43
SC4-8	5.3	0.4	64.5	2.8	2.4	0.5	0.3	11.42	9.0	4.1	15.57	89.9	<0.1	0.03	0.12	7.5	31.37	27.62
SC4-9	5.3	0.1	43.8	0.7	0.3	0.5	0.7	4.33	9.8	3.6	13 86	96.9	<0.1	0.02	0.03	1.9	11.31	10.36
SC4-11	5.3	0 2	45.6	1.0	0.6	0.5	0.6	5.08	10.0	3.0	19.08	81.4	<0 1	0.04	0.04	2.5	21.80	20.55
SC4-13	5.0	0.1	44.1	0.3	0.1	0 5	1.1	2.22	10.0	2.9	6.85	148.5	<0.1	0.01	0.02	0.6	9.33	9 03

[a]Electrical conductivity.
[b]Sodium adsorption ratio.
[c]Organic matter.
[d]Positive values indicate excess $CaCO_3$ (basic overburden material)

Table E-9. *Chemical data of overburden samples from Capps Glacier area.*

Sample	pH (paste)	EC[a] (mmhos/cm)	Saturation (%)	Organic matter (%)	Lime (%)	Extractable nutrients (ppm) NO_3	P	K	Total sulfur (%)	Acid potential (meq H^+/100 g)	Tons $CaCO_3$/1,000 tons Neutralization potential	Potential acidity[b]
CG3-1	6.6	0.9	52.4	4.27	10.1	2.1	11.32	226.3	0.09	5.6	22.97	20.17
CG3-2	6.6	0.7	67.9	8.93	9.0	4.3	9.75	147.6	0.35	21.9	26.47	15.52
CG3-3	7.8	0.6	59.3	2.55	9.5	3.6	11.69	152.1	0.02	1.3	32.65	32.00
CG3-4	7.3	0.7	24.2	1.89	7.7	3.1	10.72	84.5	0.03	1.9	213.84	212.89
CG3-5	7.4	0.6	58.2	2.61	9.9	3.7	12.07	197.4	0.04	2.5	29.03	27.78
CG3-7	7.0	0.3	50.6	4.35	9.8	4.2	7.07	208.4	0.05	3.1	41.98	40.43
CG3-8	6.3	0.6	86.6	8.89	9.4	3.4	8.71	137.7	0.38	23.8	34.16	22.26
CG3-9	6.7	0.2	54.9	2.88	9.9	2.3	15.65	169.2	0.02	1.3	17.26	16.61

[a]Electrical conductivity.
[b]Positive values indicate excess $CaCO_3$ (basic overburden material).

Table E-10. *Suitability ratings for soils as sources of topsoiling material in Wyoming. From Wyoming Department of Environmental Quality, 1980.*

Parameter	Degree of soil suitability: Good	Fair	Poor	Unsuitable
pH	6.0-8.4	5.5-6.0 8.4-8.8	5.0-5.5 8.8-9.0	<5.0 >9.0
Conductivity (EC) (mmhos/cm @ 25°C)	<4	4-8	8-16	>16
Saturation percentage (SP) (%)	25-80		>80 <25	
Texture class	SL, L, SiL, SCL	CL, SiCL, SC, LS	C, SiC, S	
Sodium adsorption ratio (SAR)	<6	6-10	10-15	>15
Calcium carbonate (%)	Low (none-slight) 0-15	Moderate 15-30	High >30	
Moist consistence	Friable	Loose, firm	Very firm	
Dry consistence	Loose, soft	Slightly hard, hard	Very hard	
Selenium (ppm)	< 2		> 2	
Boron (ppm)	< 5		> 5	
Molybdenum (ppm)	< 5		> 5	
NO_3 (ppm)	< 50 (suspect)		> 50 (suspect)	

Table E-11. *Suspect levels in overburden material of Montana. From Dollhopf and others, 1978, v. 1, p. 43.*

Parameter	Suspect level
Conductance (EC)	>4-6 mmhos/cm
Sodium adsorption ratio (SAR)	>12
Mechanical analysis	
Clay	>40%
Sand	>70%
Saturation percentage	None
pH	>8.8-9.0
PO_4	None
NO_3	>10-20 ppm
NH_4	>10-20 ppm
Cd	>0.1-1.0 ppm
Cu	>40 ppm
Fe	Unknown
Pb	pH <6, >10-15 ppm[a] pH <6, >15-20 ppm[b]
Mn	>60 ppm
Hg	>0.4-0.5 ppm
Se	>2.0 ppm
Mo	>0.3 ppm
B	>8.0 ppm
Zn	>30-40 ppm
Ni	>1.0 ppm[a] >5.0 ppm[b]

[a]DTPA extraction
[b]Acid extraction

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